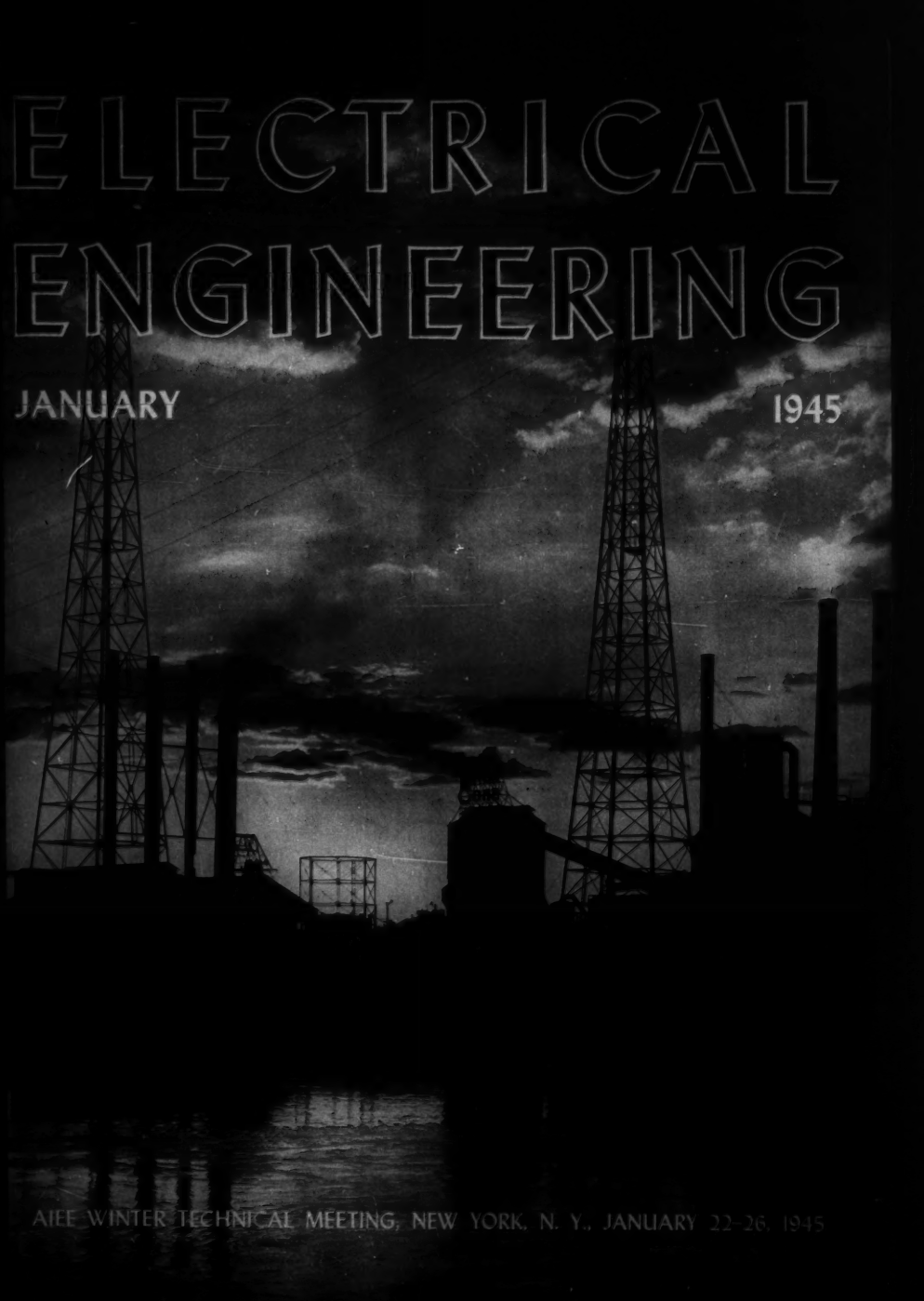
ELECTRICAL ENGINEERING

JANUARY 1945



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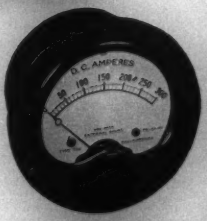

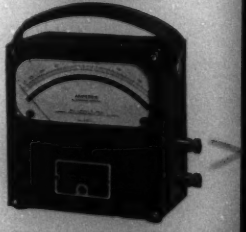

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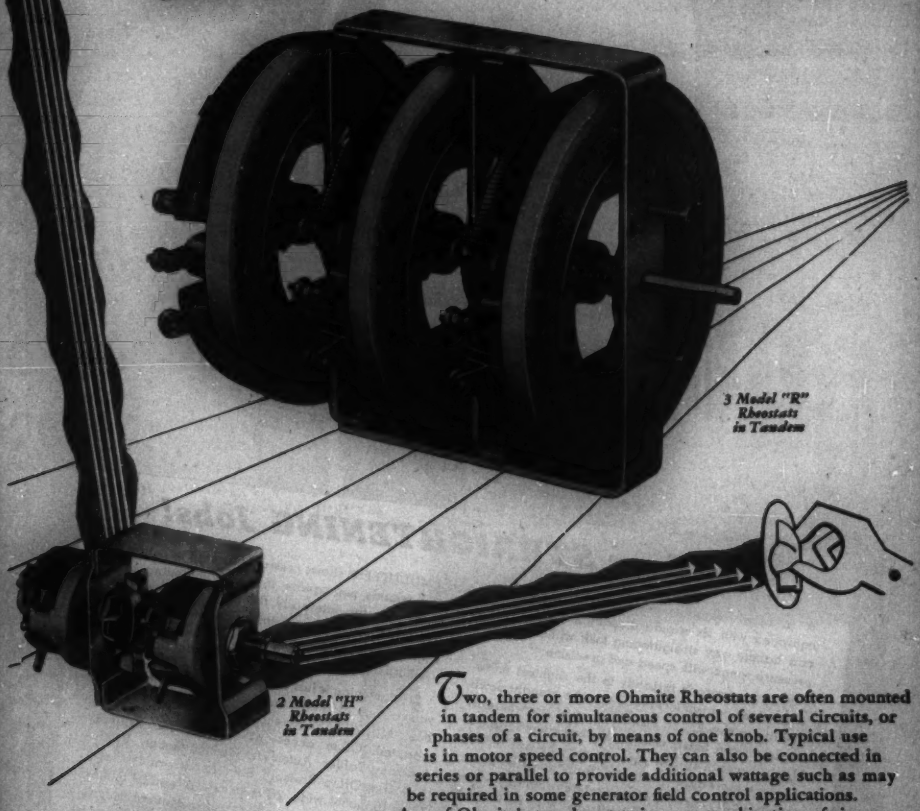

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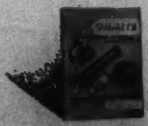

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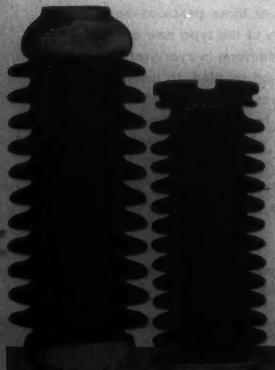

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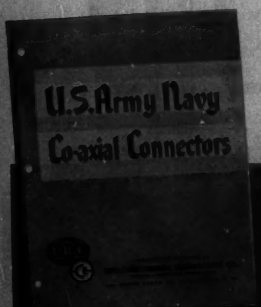

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The Cover: Transmission towers are symbols of electric power, essential to the many industries in and around New York, N. Y., where the AIEE winter technical meeting will be held January 22–26, 1945.

Grounding Principles and Practice—I ..... Reinhold Rüdenberg . . . 1

The Engineer and His Future ..... Charles A. Powel . . . 14

Lighting of Budd Field ..... J. L. Kilpatrick, L. N. Blugerman . . . 17

Recent Electron-Tube Developments ..... S. B. Ingram . . . 22

Electrical Engineering in the Postwar World—IX ..... A. W. Hull . . . 25

Miscellaneous Short Item: High Soldering Temperatures Destroy Wire, 24

Institute Activities . . . 28

Of Current Interest . . . 43

TRANSACTIONS SECTION

(Follows EE page 46; a preprint of pages 1–40 of the 1945 volume)

Evaluation of Electric Distribution Losses ..... M. Mortara . . . 1

Two-Phase Co-ordinates of a Four-Phase Network .... Edward W. Kimbark . . . 7

Subway Supervisory Control ..... W. A. Derr, C. J. Buck, J. A. Stoos . . . 10

Calculation of Distribution-System Fault Currents ..... F. W. Linder . . . 16

Simulated-High-Altitude Testing ..... H. H. Race, A. M. Ross, Jr. . . . 20

Aircraft Illumination ..... W. W. Davies . . . 26

Damping Effect of D-C Marine Propulsion Motors ..... Bernard Litman . . . 31

Speed-Control System ..... F. W. Godsey, Jr., J. D. Miner, Jr., O. C. Walley . . . 37

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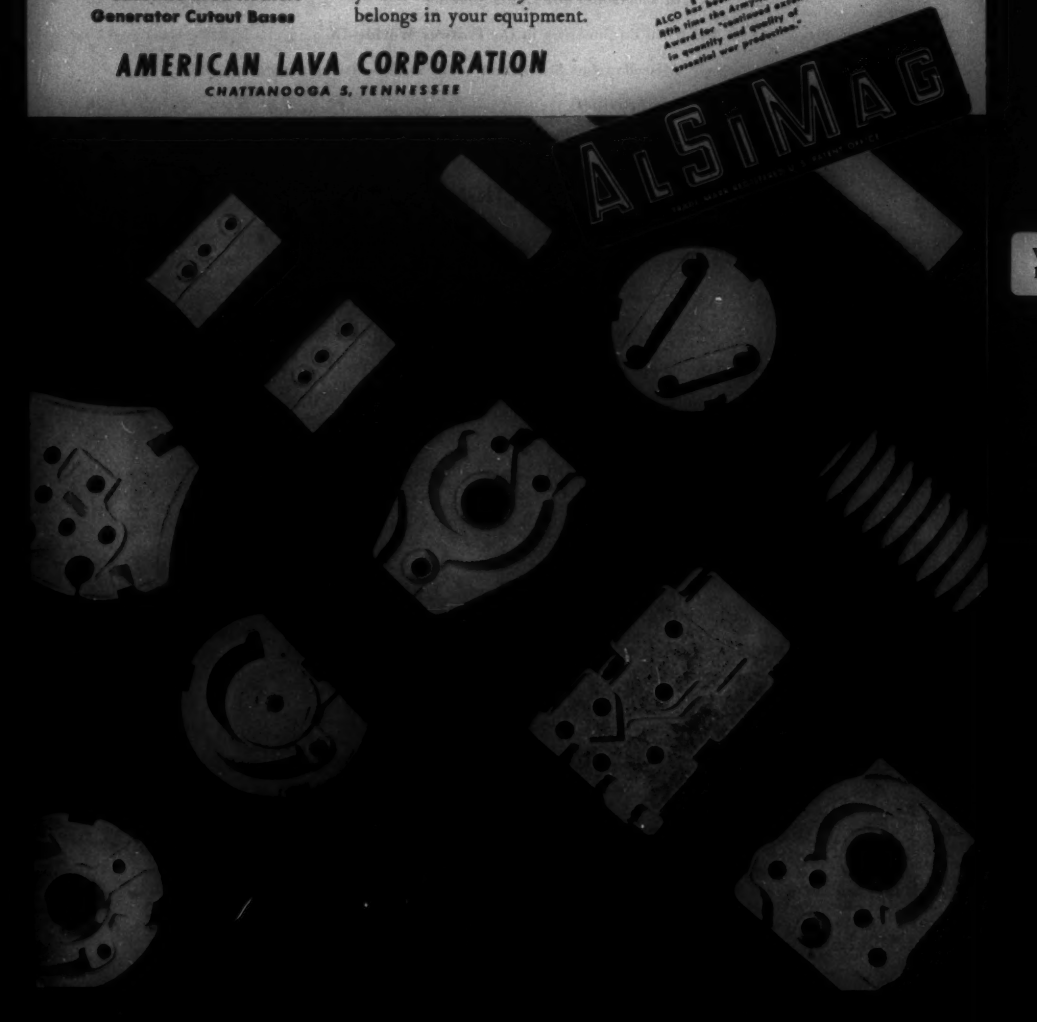


ELECTRICAL ENGINEERING
VOLUME 64, NUMBER 1 JANUARY 1945

Grounding Principles and Practice

I—Fundamental Considerations on Ground Currents

REINHOLD RÜDENBERG
MEMBER AIEE

IN THIS ARTICLE are considered the main scientific problems related to the conduction of electric currents to the earth and through the ground. While the overall performance of an electric system in which one or more points are grounded depends on the behavior of the wire network and the ground, this article is confined to the underground flow of the electric currents, which is not so easily measurable and therefore not so well understood as the behavior of the currents in the overhead network.

The earth is a body of three dimensions and therefore the beautiful simplicity of the linear wires by which electric currents usually are directed is lost. In the earth the currents spread out in the entire space, and it is necessary to follow their paths in order to analyze their performance in the underground.

The earth has been used as a conductor for electric currents since the beginning of engineering. However, after a brief period of preference for sending return currents through the ground, great difficulties and hazards were found from this in all branches of electrical engineering. Nowadays the earth is used mainly for fixing the neutral point of the electric system, and in many instances the inclusion of the earth as part of the circuit cannot be avoided.

RESISTANCE OF THE SOIL

Geological Strata. The electric conductivity of the materials constituting the earth's surface is very low compared with the high conductivity of the metals. Two main constituents of the earth, silicon oxide and aluminum oxide, actually are excellent insulators, and the conductivity of the ground is due in large measure to salts and moisture embedded between these insulators. On the other hand, even a semiconductor may carry a considerable amount of current if only the cross section is large enough, and in this respect the earth, by its great depth, presents no limitations.

Reinhold Rüdenberg is Gordon McKay professor of electrical engineering in the graduate school of engineering, Harvard University, Cambridge, Mass.

This article is the first of five based on a series of lectures which was sponsored by the power and industrial group of the AIEE New York Section during the 1943–44 season. The behavior of currents flowing in the earth, as influenced by the resistivity of the soil, frequency of the current, and size and shape of electrodes, is analyzed here.

Because of the high resistivity, all currents flowing through the ground suffer a considerable voltage drop. Therefore we must break with the popular concept that the potential of the ground is always zero. A substantial electric-field strength, or potential gradient, can develop and this may affect extended regions of the earth's surface. We have to distinguish between two different zones which will be considered in detail, namely, the spaces in proximity to the ground electrodes and the long path between such electrodes.

The ground under the surface of the earth is by no means homogeneous, and this makes a rigorous analysis of the distribution of currents very difficult if not impossible. Figure 1 represents a typical geological cross section of the underground indicating the great heterogeneity of the conducting body through which electric currents may pass. Random changes caused by weather and seasons, by rain, frost, and by other temperature variations, with their influence on the conductivity of the soil, increase the difficulty of analysis. It would not be wise, therefore, to develop here the laborious considerations for a very high degree of accuracy. However, a quantitative analysis of the electric phenomena in the ground is necessary in order to make numerical calculations and to draw definite conclusions if the electric system from time to time shall not experience technical trouble or cause serious accidents.

Variation of Earth Resistivity. The resistivity of the soil depends on many parameters. It depends on the type of soil and therefore varies with distance as well as with depth, as indicated by Figure 1. Further, the resistivity is much smaller below the subsoil water level than above it. In frozen soil, as in the surface layer in winter, it is particularly high. It is important, therefore, for good ground electrodes to avoid the frost limit and to reach the subsoil water plane. Figure 2 shows the variation of resistivity ρ of a certain soil as measured (*a*) versus moisture content, (*b*) versus temperature change, and (*c*) versus added salt in per cent of weight. It is seen by the logarithmic scales used that these three parameters affect the earth resistivity by several powers of ten, thus very large variations may occur.

Attempts have been made to correlate the resistivity with the geological age of the strata. Although older material in general has higher resistivity, many exceptions were found. In the actual strata under the surface, loam, clay, and limestone usually have lower resistivity; sandy and rocky materials have higher resistivity. While for power networks and for radio waves the resistivity near the surface is more important, for telephone interference by action at a distance the resistivity of the deeper layers has greater significance.

SPHERICAL GROUND ELECTRODES

Current Paths and Grounding Resistance. There will be considered first the simpler electrode elements and later some of the more complex combinations used in practice. For quantitative calculations the meter-kilogram-second system will be used which leads directly to the practical electric units.

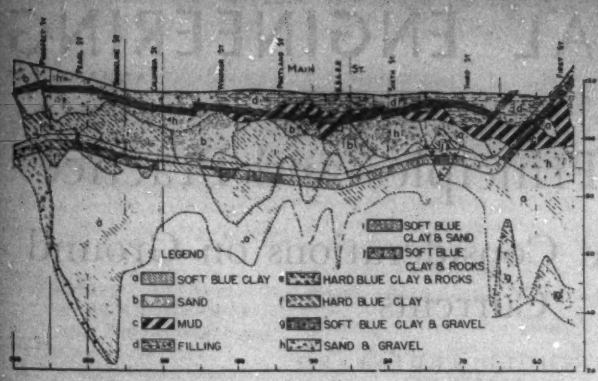


Figure 1. Subsoil strata under Main Street, Cambridge, Mass.

The simplest possible electrode is shown in Figure 3, namely, a sphere in the ground which is symmetrical in all directions. It may be entirely embedded in the ground, or only the lower hemisphere embedded in the half space of ground under the surface plane of the earth, a case which will be considered. If a current I flows through this electrode, spreading out radially in the ground, the current density at distance x from the center of the hemisphere is

$$i = \frac{I}{2\pi x^2} \tag{1}$$

According to Ohm's law such a current produces in the resistivity ρ of the soil an electric-field strength

$$e = \rho i = \frac{\rho I}{2\pi x^2} \tag{2}$$

The voltage, as line integral of the field strength from the surface of the conducting sphere of radius B to the distance x, is therefore

$$E = \int_B^x e\,dx = \frac{\rho I}{2\pi}\int_B^x \frac{dx}{x^2} = \frac{\rho I}{2\pi}\left[\frac{1}{B} - \frac{1}{x}\right] \tag{3}$$

Current density, field strength, and voltage, in their dependence on distance, are represented graphically near the top of Figure 3.

The total voltage between the spherical electrode and a far distant point with $x = \infty$ is, according to equation 3,

$$E = \frac{\rho I}{2\pi B} \tag{4}$$

and therefore the resistance experienced by the streamlines of current diverging from the hemisphere is

$$R = \frac{E}{I} = \frac{\rho}{2\pi B} \tag{5}$$

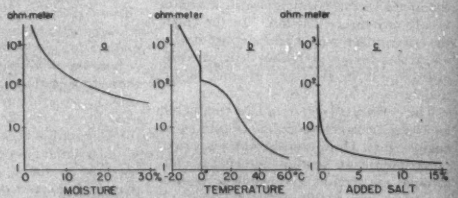
Any additional resistance due to incomplete contact of the electrode and the ground occurs only rarely in practice.

If we consider, for a numerical example, a hemispherical electrode of radius $B = 1$ meter embedded at the surface of the earth of resistivity $\rho = 10^2$ ohm-meter, the ground resistance of this electrode will be

$$R = \frac{10^2 \text{ ohm-m}}{2\pi \cdot 1\text{m}} = 16 \text{ ohms}$$

As the curves in Figure 3 show, this resistance is distributed over the entire half space; however, the major part of it is concentrated in proximity to the electrode.

Figure 2. Resistivity of the earth depending on moisture, temperature, and salt contents



If two such electrodes are used through which the current enters and leaves the ground, the streamlines of the current develop as superposition of two hemispherical current distributions. This is shown in Figure 4a under the assumption that the resistivity of the soil is uniform in space. If a voltage of 110 volts is impressed between the electrodes, one having a diameter of 10 meters and the other of 1 meter, and separated by a distance of 1,000 meters, the streamlines and equipotential lines develop as shown in Figure 4a, and concentrate mainly around the smaller electrode.

If, on the other hand, a more highly conducting layer should exist at the surface of the earth, for example after a heavy rain, then the streamlines do not develop in depth but remain near the surface. Their shape within this layer and the distribution of potential are shown in Figure 4b for electrodes of the same dimensions and distance apart as before. Here the voltage does not concentrate so heavily near the electrodes but spreads out over larger areas of the surface.

Field Strength on Surface. If a man or an animal is walking through such a surface field of electric potential, for example in the neighborhood of a faulty transmission tower, as shown in Figure 5, the body diverts some current from the earth and may suffer damage from the potential gradient. The tower footing carrying a current I to the ground can be represented for the present purposes by an equivalent hemisphere of radius B, as shown by the dotted line in Figure 5. The field strength on the surface of the ground is then given by equation 2 and increases toward the tower to a maximum value at distance B

$$e_B = \frac{\rho I}{2\pi B^2} \tag{6}$$

With the figures of the former example and with a tower current to ground $I = 100$ amperes, the maximum field strength at the surface is

$$e = \frac{10^2 \text{ ohm-m} \cdot 100 \text{ amp}}{2\pi \cdot (1\text{m})^2} = 1{,}600 \text{ volts per meter}$$

a remarkably high value.

This field strength produces a current in any living creature stepping over the surface. The maximum possible current develops if the internal body resistance is small compared with the foot resistance on the ground, which is

$$r = \frac{\rho}{2\pi b} \tag{7}$$

if b signifies the equivalent radius of the creature's foot. For a man's foot this has been measured in an electrolytic trough as $b = 7$ centimeters on the average. Since the voltage drop by the body current through the resistance $2r$ due to both feet is given by the voltage taken over the step length s

$$2ri_s = es \tag{8}$$

and therefore the maximum body current becomes

$$i_s = \frac{es}{2r} = \frac{\pi bes}{\rho} = \frac{sb}{2x^2} I \tag{9}$$

if expressed in terms of the tower current I.

With the numerical values already used, there is obtained for a man taking a step one meter long at a distance of three meters from the center of the tower, a body current

$$i_s = \frac{1\text{m} \cdot 0.07\text{m} \cdot 100\text{ amp}}{2 \cdot (3\text{m})^2} = 0.39 \text{ ampere}$$

and this maximum current is certainly deadly.

Measurements by Probes. Measurements of ground resistance require some considera-

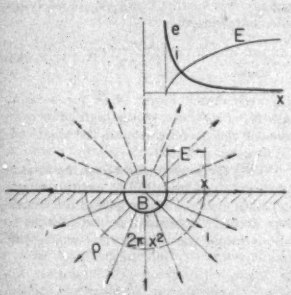


Figure 3. Radial flow of current from spherical electrode to ground

tion. Care should be taken that probes or auxiliary electrodes, as in Figure 6, are sufficiently far removed from the spreading-out zone of the main current, if the probes are to measure the entire resistance experienced by the current. The voltage E will be independent of the distance x between the main and auxiliary electrodes only if x is much greater than both b and B.

By application of equation 3 to both systems of current distribution of Figure 6 around the hemispheres of radii B and b, superposition gives the voltage between the two electrodes. Thus the total resistance is

$$\frac{E}{I} = \frac{\rho}{2\pi}\left[\frac{1}{B} + \frac{1}{b} - \frac{2}{x}\right] \tag{10}$$

which is smaller than the sum of the resistances R and r proper of the two electrodes. By equation 10, ρ can be determined from the measured quotient of voltage and current if the dimensions are known and if ρ is constant over the ground. If this latter cannot be assumed, the resistivity around the smaller electrode nevertheless can be measured if its radius b is made so small that it is much less than both B and x, so that not only the last term but also the first term in the bracket of equation 10 becomes negligible. This gives the resistivity

$$\rho = 2\pi b \frac{E}{I} \tag{11}$$

as determined only by the quotient of voltage and current and the linear dimension b of the probe. In this way numerous measurements have been performed showing that there are very great differences in the resistivity of the natural soil.

If no specific measurements for a definite spot of ground are made, the figures of Table I may be used as average resistivity over the underground.

Two Parallel Ground Electrodes. If two electrodes are arranged mutually within their spaces of high field strength, as in Figure 7, they experience mutual influence. For each of the spheres in Figure 7 the voltage from the sphere of radius b through distance y is, by equation 3,

$$E = \frac{\rho I}{4\pi}\left[\frac{1}{b} - \frac{1}{y}\right] = V_b - V \tag{12}$$

Since the voltage is determined by the difference in the bracket, which depends only on distances, the voltage can be expressed by the difference of two potentials, as on the right-hand side of equation 12. The potential V of a spherical source of current in space is therefore

$$V = \frac{\rho I}{4\pi y} \tag{13}$$

and such potentials always superpose if more than one source is present.

In the center plane between the two spheres of Figure 7, the potential is therefore

$$V_z = 2\,\frac{\rho I}{4\pi y} \tag{14}$$

if both spheres carry equal currents I to the ground. On the other hand, at the surface of either sphere the self-potential is determined by the radius b, the mutual potential by the average distance $2z$ between the centers of the spheres. The total potential is therefore

$$V = E = \frac{\rho}{4\pi}\left(\frac{I}{b} + \frac{I}{2z}\right) = \frac{\rho I}{4\pi b}\left(1 + \frac{b}{2z}\right) \tag{15}$$

Hence the resistance of two spheres in parallel in the ground, carrying together the current $2I$, is

$$R = \frac{E}{2I} = \frac{\rho}{4\pi b}\cdot\frac{1}{2}\left(1 + \frac{b}{2z}\right) \tag{16}$$

The first quotient, by comparison with equation 5, gives the ground resistance of one sphere. The last factor for far-distant electrodes with $z = \infty$ becomes $1/2$; but for close electrodes, for example, with $z = b$ becomes $1/2(1+1/2) = 3/4$. Thus distant spheres are mutually independent in their resistances and their parallel resistance can be computed according to ordinary rules. Close electrodes, however, experience an increase of their ground resistance by mutual interference.

Table I. Average Resistivity of the Ground

Type of Ground	Resistivity ρ, Ohm-Meters
Wet organic soil	10
Moist soil	10^2
Dry soil	10^3
Bed rock	10^4

Depth Electrode. Figure 8 shows a spherical electrode buried in depth. Considering the arrangement of Figure 8 as half that of Figure 7, we obtain the resistance of such a depth electrode as twice that of equation 16, namely,

$$R = \frac{E}{I} = \frac{\rho}{4\pi b}\left(1 + \frac{b}{2z}\right) \tag{17}$$

Near the surface, for example at $z = b/2$, we have $\left(1 + \frac{b}{2b/2}\right) = 2$, and the resistance becomes the same as with equation 5. Under the surface the resistance decreases and in greater depth the correction term $b/2z$ vanishes, thus cutting the resistance in half.

With a depth electrode the space of high current concentration is not accessible to creatures, thus the danger of stepping near the electrode decreases. At any point of the surface, as seen by Figure 8,

$$\frac{x}{y} = \sin\alpha = \frac{dy}{dx} \tag{18}$$

where x is the distance from the axis of the depth electrode and α the corresponding central angle. Thus the field strength at the surface is

$$e = \frac{dV_z}{dx} = \frac{dV_z}{dy}\sin\alpha \tag{19}$$

Substituting the potential V_z from equation 14, we obtain the field strength at the surface

$$e = \frac{\rho I}{2\pi}\,\frac{d(1/y)}{dy}\sin\alpha = \frac{\rho I}{2\pi}\,\frac{\sin\alpha}{y^2} \tag{20}$$

Now, for α near 90 degrees, $\sin\alpha/y^2 = 1/x^2$; while for small values of α, $\sin\alpha/y^2 = x/z^3$. Therefore the field strength at large distances decreases exactly like that around a hemisphere, while vertically over the depth electrode the field strength becomes zero and rises linearly for small values of x. At an angle determined by $\tan\alpha = 1/\sqrt{2}$, the field strength is a maximum, namely,

$$e = \frac{\rho I}{3\sqrt{3}\pi z^2} \tag{21}$$

The ratio of this value to the maximum value of equation 6 for a surface electrode is

$$\frac{2}{3\sqrt{3}}\left(\frac{b}{z}\right)^2 = 0.39\left(\frac{b}{z}\right)^2 \tag{22}$$

which shows that a depth electrode, for sufficiently large depth z, minimizes the danger for stepping creatures.

ROD AND WIRE ELECTRODES

Driven Rod at Earth Surface. Spherical or hemispherical electrodes are not con-

venient for actual use. In practice rod or wire electrodes, having a relatively small cross section compared with the length, are preferred. We may subdivide with good approximation such a rod electrode driven into the ground, as in Figure 9, into a large number n of nearly spherical elements, which over the length l of the rod in the ground have a mutual distance

$$dl = \frac{l}{n} \tag{23}$$

each feeding a current I/n into the ground. If y is the distance from any element to a point at the surface of the earth and α is the angle from y to the axis of the rod, the small diagram in Figure 9 shows that

$$\sin \alpha = \frac{y d\alpha}{dl} \tag{24}$$

The potential dV of every element is given by equation 13 with current I/n. By substitution of the distance y from equation 24, and use of equation 23, the incremental potential at the surface of the earth becomes

$$dV = \frac{\rho I/n}{4\pi y} = \frac{\rho I}{4\pi n l} \frac{n}{\sin \alpha} \frac{d\alpha}{} \tag{25}$$

If the limiting value of angle α is denoted by β, as shown in Figure 9, the potential in the center plane of a rod of length $2l$, containing $2n$ spheres and thus including the fictitious image above the ground, is given by the integral of dV from $+\beta$ to $-\beta$,

$$V = \frac{\rho I}{4\pi l} \int_{+\beta}^{-\beta} \frac{d\alpha}{\sin \alpha} = \frac{\rho I}{2\pi l} \log_e \left(\cot \frac{\beta}{2} \right) \tag{26}$$

This result would be rigorous if the density of the current emerging from the rod into the earth were uniform over the length, which actually is only a fair approximation.

The electric potential in the symmetry plane of the driven rod thus is dependent on only four parameters, namely: resistivity ρ of the ground, current I flowing into the rod, its length l within the ground, three data which are always given for a definite ground electrode, and the angle of vision β between the axis of the rod and the distance from the bottom of the rod to the point under consideration at the surface. For any point in this center plane β is the only variable parameter.

For large distance x of the point considered from the axis of the rod, the logarithm in equation 26 simplifies to

$$\log_e \left(\frac{1+\cos \beta}{\sin \beta} \right) \approx \cos \beta \approx \frac{l}{x} \tag{27}$$

and the potential is

$$V_\infty = \frac{\rho I}{2\pi x} \tag{28}$$

which is identical with that for a hemisphere.

On the other hand, for the surface of the rod, where the potential V is identical with the voltage E of the electrode, Figure 10 shows that for small radius a as compared to length l

$$\cot \frac{\beta}{2} \approx \frac{2l}{a} \tag{29}$$

Hence the resistance as quotient of voltage and current is

$$R = \frac{E}{I} = \frac{\rho}{2\pi l} \log_e \left(\frac{2l}{a} \right) \tag{30}$$

While the shape of the rod, determining the ratio l/a, is of minor significance since it forms only the argument of a logarithm, the length l of the rod is of major importance, for the ground resistance is nearly inversely proportional to the length.

A rod of radius $a = 2.5$ centimeters and of length $l = 6$ meters, dimensions often used in practice, driven into moist soil will present a resistance

$$R = \frac{10^2 \text{ ohm-m}}{2\pi \cdot 6\text{m}} \log_e \left(\frac{2 \cdot 6}{2.5 \cdot 10^{-2}} \right)$$
$$= 2.65 \cdot \log_e 480 = 16 \text{ ohms}$$

This value equals that for a hemisphere two meters in diameter.

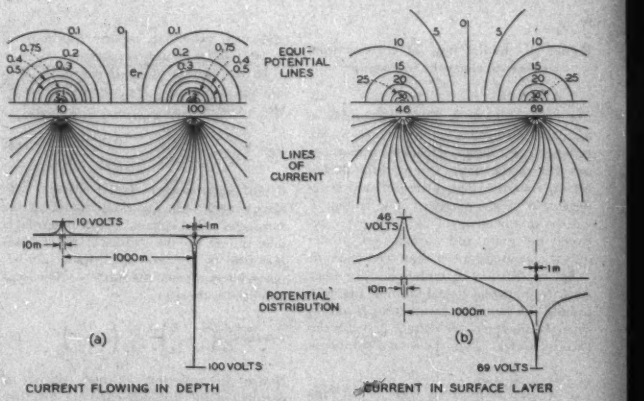


Figure 4. Flow of current between two ground electrodes

Field Strength Around Rod Electrode. On the surface of the ground there develops, according to Figure 11, a field strength

$$\epsilon = \frac{dV}{dx} = \frac{dV}{d\beta} \frac{d\beta}{dx} \tag{31}$$

where the angle β is introduced as the variable. It is correlated to x by

$$\left. \begin{aligned} \tan \beta &= \frac{x}{l} \\ \frac{dx}{d\beta} &= \frac{l}{\cos^2 \beta} \end{aligned} \right\} \tag{32}$$

where the last expression is merely the derivative of the first. Differentiation of equation 26 with respect to β and substitution of equation 32 into equation 31 gives the field strength

$$\epsilon = \frac{\rho I}{4\pi l} \frac{2}{\sin \beta} \frac{\cos^2 \beta}{l} = \frac{\rho I}{2\pi l} \frac{\cos \beta}{x} \tag{33}$$

which is decreasing with both increased x and β.

For large distance x, $\cos \beta = l/x$, approximately, and the field strength

$$\epsilon_\infty = \frac{\rho I}{2\pi x^2} \tag{34}$$

becomes identical with that for a hemisphere. For small x, however, $\cos \beta \approx 1$, and the field strength

$$\epsilon_0 = \frac{\rho I}{2\pi l x} \tag{35}$$

becomes much larger than for a hemisphere. This is due to the high concentration of the current around the small circumference of a rod.

Along the length of the rod the density of the current from rod to earth is nearly constant over the major part of the length, but actually increases at the bottom to about double the value at the center plane, due to the point effect of the end of the rod.

Simple Forms of Ground Electrodes. In a similar way the potential and the ground resistance of other forms of electrodes can be derived by superposition of spherical or cylindrical elements. Table II gives a survey of some simple forms of ground electrode. We see that a flat strip follows a relation quite like that of a circular rod and a strip thus is equivalent to a rod or a wire of a diameter equal to half the width of the strip.

The resistance of a ring of wire, having a periphery $2\pi b$, is only slightly greater than that of a straight wire of length $2l = 2\pi b$,

the increase being due to the absence of the ends of the rod with their higher current density.

The resistance of a ground electrode near the surface of the earth is always twice the resistance of that electrode in greater depth, because the distribution of the current through the upper semispace is cut off.

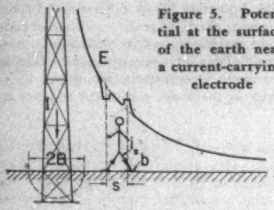


Figure 5. Potential at the surface of the earth near a current-carrying electrode

As all the equations show, the resistance is determined primarily by the largest dimension of the electrode and only to a minor extent by the smaller dimensions, like cross section or thickness. Thus the surface of the electrode is unimportant and only the linear extension matters.

The simplest method for determining the resistance of a complicated shape of ground electrode, as for example the tower footing of a high-voltage line, or of a radio antenna, often consists in measuring the resistance of a scale model of the structure in an electrolytic trough. Then the resistance of the actual device is lower in the ratio of the linear dimensions and higher in the ratio of the resistivities of the surrounding medium. The radius of the equivalent hemisphere is always a convenient means of comparison.

Four-Point-Star Electrode. For some structures frequently used which are composed of several rods or wires, it is convenient to derive analytical formulas. In a four-point-star electrode, as in Figure 12, the self-potential of every straight wire of length $2l$ is, according to equations 26 and 29,

$$V_0 = \frac{\rho I}{2\pi l} \log_e \left(\frac{2l}{a}\right) \tag{36}$$

This is to be increased by the mutual potential between the transverse wires of the cross. Equation 26 gives the potential of a wire of length $2l$ in its center plane. For angles $\beta \leqq 45$ degrees, as in Figure 12,

$$\cot \frac{\beta}{2} \geqq \frac{2l}{x} \tag{37}$$

The mean value of the logarithm of $2l/x$ over the length l of the wire is

$$\frac{1}{l}\int_0^l \log_e\left(\frac{2l}{x}\right) dx = -2\int_\infty^1 \log_e \xi \cdot d\frac{1}{\xi}$$
$$= -2\int_\infty^1 \frac{\log_e \xi \cdot d\xi}{\xi^2} = 2\left[\frac{\log_e \xi}{\xi} + \frac{1}{\xi}\right]_\infty^1$$
$$= \log_e 2 + 1 \tag{38}$$

Thus the mean mutual potential between the crossed wires is

$$V_1 \approx \frac{\rho I}{2\pi l}(\log_e 2 + 1) \tag{39}$$

The voltage E of every conductor is given by the sum of the potentials or

$$E = V_0 + V_1 \approx \frac{\rho I}{2\pi l}\left[\log_e\left(\frac{2l}{a}\right) + \log_e 2 + 1\right] \tag{40}$$

and therefore the resistance to ground of the entire four-point-star electrode is

$$R = \frac{E}{4I} \approx \frac{\rho}{8\pi l}\left[\log_e\left(\frac{4l}{a}\right) + 1\right] \tag{41}$$

If such a star of wires is embedded near the surface of the earth at a depth small compared with the length dimension of the electrode, the ground resistance is twice that of equation 41 as indicated in the last example of Table II.

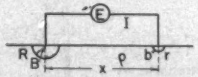


Figure 6. Measurement of the resistivity of the soil

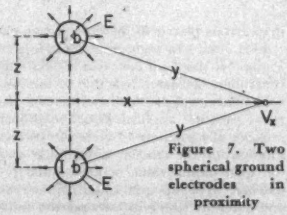


Figure 7. Two spherical ground electrodes in proximity

The value of the resistance of equation 41, by the addition of unity to the logarithm in the bracket, is slightly greater than for a straight wire of length $4l$. This increase is due to the mutual influence of the current distributions in the ground caused by neighboring parts of the entire electrode. With more star wires than four, such influence increases, preventing the resistance from being reduced in proportion to the increase of the number of the wires. For many wires, finally forming a circular disk, the resistance approaches

$$R = \frac{\rho}{8l} \tag{42}$$

For average values of the ratio radius to length of the wire, a comparison of equation 42 with equation 41 shows that by increasing the number of radial wires to infinity the resistance reduces to only

$$\frac{R^a}{R^+} = \frac{\pi}{\log_e\left(\frac{4l}{a}\right) + 1} \approx \frac{\pi}{9.3} \approx \frac{1}{3} \tag{43}$$

of that of the simple four-wire star. The gain with increasing number of wires is not very great.

Multiple Rod Electrodes. Another combined electrode frequently used, namely, multiple driven rods connected in parallel, is shown in Figure 13. The potential at the earth's surface of every rod again is given by the general equation 26. The voltage at each of the electrodes is given by the sum of all the potentials produced by the rod considered and all the other rods. For rod number one, for example, the voltage is

$$E_1 = \frac{\rho}{2\pi l}\left[I_1 \log_e\left(\cot\frac{\beta_1}{2}\right) + I_2 \log_e\left(\cot\frac{\beta_2}{2}\right) + \dots\right] \tag{44}$$

The currents of the rods are not yet determined, but for the sake of simplicity the resistivity of the soil and the length of all the rods have been taken as uniform. As many equations of this type can be developed as there are rods in the electrode, the angles β signifying always the angles of vision from the bottom of each rod toward the top of the rod considered as seen by Figure 13. Therefore, for any arrangement of driven rods a sufficient number of equations is obtained to determine the distribution of the currents among the individual rods of the electrode.

The first cotangent of equation 44 refers to the rod considered and can be evaluated by equation 29. The further cotangents, which refer to the other rods, can be expressed, as shown in Figure 13, by the ratio of the length l of the rod to a distance s_n, cut off by the angle $\beta/2$ on the distance S_n between the rods. Thus

$$\left.\begin{aligned} \cot\frac{\beta_1}{2} &= \frac{l}{a/2} \\ \cot\frac{\beta_n}{2} &= \frac{l}{s_n} \end{aligned}\right\} \tag{45}$$

If the rods are connected by zero resistance and are located symmetrically with

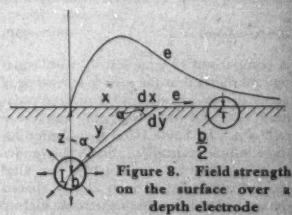


Figure 8. Field strength on the surface over a depth electrode

respect to one another, the voltages and currents are

$$E_1 = E_2 = E_3 \dots = E; \quad I_1 = I_2 = I_3 \dots = \frac{I}{n} \tag{46}$$

Therefore, with use of equation 45, all the equations 44 take the form

$$E = \frac{\rho}{2\pi l}\frac{I}{n}\left[\log_e\left(\frac{l}{a/2}\cdot\frac{l}{s_2}\cdot\frac{l}{s_3}\dots\right)\right] \tag{47}$$

For each case equation 47 can be evaluated easily, but three significant examples may be considered in detail.

For large ratio S/l, with the rods distant from one another, evidently $\beta_n/2 = 45$ degrees and $s_n = l$. Thus all the quotients $l/s = 1$, and the combined resistance is

$$R = \frac{E}{I} = \frac{1}{n} \cdot \frac{\rho}{2\pi l} \log_e \left(\frac{2l}{a}\right) \qquad (48)$$

In this case the ohmic value is reduced in inverse proportion to the number of parallel rods.

For small ratio S/l, with the rods close together, the angles β are small, and therefore always $s_n = S_n/2$, see Figure 13. Hence, if the number of rods n is placed under the logarithm, the resistance becomes

$$R = \frac{\rho}{2\pi l} \log_e \left(\frac{2l}{\sqrt[n]{a S_2 S_3 S_4 \dots}} \right) = \frac{\rho}{2\pi l} \log_e \left(\frac{2l}{A}\right) \qquad (49)$$

In the right-hand term we have expressed the nth root of the product of the distances between all of the electrodes and the first electrode including the radius of the first electrode, by the geometric mean distance

$$A = \sqrt[n]{a S_2 S_3 S_4 \dots} \qquad (50)$$

A comparison of equation 49 with equation 30 shows that the sum of several or of many driven rod electrodes in close proximity acts as if there were only one rod of radius A. In Table III A is evaluated for three simple examples. Since A is under the logarithm in equation 49, the total ground resistance of such closely spaced electrodes becomes diminished only slightly with increased number of rods.

For medium ratio $S/l = 1$, where the rods are driven at distances equal to their length, evidently $\beta_n = 45$ degrees, and thus $\cot \beta_n/2 = 2.4$. For example, if $n = 3$ rods, the characteristic part of equation 47 becomes

$$\frac{1}{3} \log_e \left(\frac{l}{a/2} \cdot 2.4 \cdot 2.4 \right)$$

and for values of $l = 6$ meters, $a = 2.5$ centimeters, $\rho = 10^4$ ohm-meters as in the former examples, the resistance is

$$R = \frac{2.65}{3} \log_e (480 \cdot 2.4^2) = 7.0 \text{ ohms}$$

If the rods were far apart, $S = \infty$, the resistance would be $^{16}/_3 = 5.3$ ohms. Thus three rods with separation equal to their length experience a mutual influence which increases their resistance by 32 per cent.

In order to obtain low ground resistance in bad soil of high resistivity, it is often necessary to arrange for quite a number of driven rods placed in lines or over an extended area. In such ground beds, as in Figure 14, the inner rods carry lower currents than the outer rods due to the mutual influence of the surrounding rods. In every case the application of the proper number of equations 44 gives the correct solution for the current distribution and the total ohmic value of the ground resistance. Even unequal lengths of the rods and different resistivity around the individual rods easily can be taken into account.

Depth Measurement. Frequently the resistivity ρ varies not only from rod to rod but also with the depth for each rod. In order to obtain a survey of such variation, it is useful to measure the ground resistance during the driving of the individual rods.

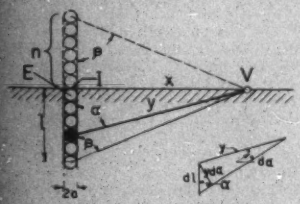


Figure 9. Development of the potential around a rod electrode

Figure 10 (left). Dimensions of a driven rod

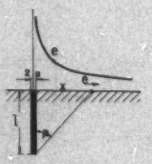


Figure 11 (right). Field strength on the surface around a driven rod

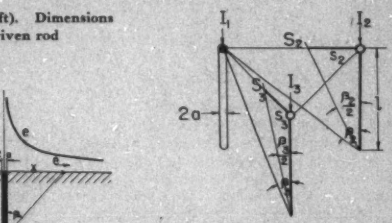


Figure 13. Driven rods in parallel

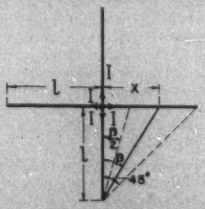


Figure 12. Four-point-star electrode in the ground

The ground conductance of a rod, as reciprocal of the resistance, equation 30, is

$$G = \frac{2\pi l}{\rho \cdot \log_e \left(\frac{2l}{a}\right)} \qquad (51)$$

As indicated in Figure 15, the increment of conductance with lengthening of the rod by an element dx is therefore

$$dG = \frac{2\pi \cdot dl}{\rho \cdot \log_e \left(\frac{2l}{a}\right)} \qquad (52)$$

The logarithm is not differentiated since it was derived under the condition of constant resistivity and its variation is very small under any circumstances. During the depth measurement the actual resistivity at the lower end of the rod over an increment of length dx is, by equation 52,

$$\rho = \frac{2\pi}{\log_e \left(\frac{2l}{a}\right)} \cdot \frac{dl}{dG} \qquad (53)$$

Thus ρ is inversely proportional to the derivative of the conductance which is shown as dashed curve in Figure 16b.

With respect to the resistance R,

$$\left.\begin{aligned} G &= \frac{1}{R} \\ dG &= -\frac{dR}{R^2} \end{aligned}\right\} \qquad (54)$$

and thus the resistivity at the lower end, dependent on the derivative of the resistance curve in Figure 16b, is

$$\rho = \frac{2\pi}{\log_e \left(\frac{2l}{a}\right)} \cdot \frac{R^2}{-\frac{dR}{dl}} \qquad (55)$$

Figure 16a indicates that a small derivative is measured through a stratum of high resistivity, a large derivative through a stratum of low resistivity.

If a rod of radius $a = 2.5$ centimeters is driven step by step into the depth and if at length $l = 6$ meters, the resistance is measured as $R = 16$ ohms and the derivative as $dR/dl = -0.15$ ohm per meter, the resistivity at that depth will be

$$\rho = \frac{2\pi}{\log_e (480)} \cdot \frac{16^2}{0.15} = 174 \text{ ohm-meter}$$

By such continuous measurements of resistance during the driving of a bed of rods, it is possible to obtain information about

the resistance strata of the earth in which the ground electrodes have to function.

HEATING OF THE GROUND

If a ground electrode is to be loaded continuously, or even over a short time only, the temperature rise θ of the soil must be considered in order to avoid an overloading which might evaporate the moisture. The current density about a spherical electrode with radius B embedded in the ground varies over the distance x as

$$i=\frac{I}{4\pi x^2} \tag{56}$$

as is indicated in Figure 17. Thereby an amount of heat ρi^2 is produced in every element of volume, which may be considerable because of the high value of the resistivity ρ. This heat is partly stored in the volume elements of the ground, which have an average specific heat $\gamma \approx 1.75 \cdot 10^6$ ws/m^3C (watt-seconds/meter^3·degrees centigrade); partly conducted from higher to lower temperature within the ground, the average heat conductivity being $\lambda \approx 1.2$ w/mC (watts/meter·degrees centigrade). Although these two thermal constants of the soil are of major significance, their actual values seldom have been measured accurately.

The differential equation of the radial heat conduction about a sphere is

$$\gamma\frac{d\theta}{dt}-\frac{\lambda}{x}\frac{d^2(x\theta)}{dx^2}=\rho i^2 \tag{57}$$

It is difficult to obtain a general solution of this equation since i varies with x. However, we can discuss two interesting phases of the heating, giving particular integrals, namely the steady state and the short-time state.

Steady-State Heating. For continuous ground currents the time derivative in

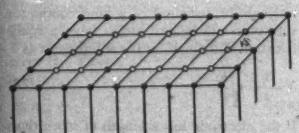


Figure 14. Extended bed of rod electrodes

equation 57 vanishes, and the differential equation becomes

$$\lambda\frac{d^2(x\theta)}{dx^2}+\frac{\rho}{x^2}\left(\frac{I}{4\pi}\right)^2=0 \tag{58}$$

With two simple integrations the solution for the temperature distribution over distance x becomes

$$\theta=\frac{\rho}{\lambda}\left(\frac{I}{4\pi}\right)^2\frac{1}{x}\left(\frac{1}{B}-\frac{1}{2x}\right) \tag{59}$$

which is plotted against x in Figure 17. The maximum earth temperature at the electrode with $x=B$ is

$$\theta_B=\frac{1}{2}\frac{\rho}{\lambda}\left(\frac{I}{4\pi B}\right)^2 \tag{60}$$

and depends only on the two constants ρ and λ of the ground and on the linear current density I/B. The admissible current to ground from the spherical electrode is therefore

$$I=4\pi B\sqrt{2\frac{\lambda}{\rho}\theta}=\frac{1}{R}\sqrt{2\rho\lambda\theta} \tag{61}$$

where the right-hand term is obtained by substituting the resistance $R=\rho/4\pi B$. The current-carrying capacity of the electrode is thus determined, in addition to the ground constants, by resistance and temperature rise θ only.

Since the heat flow and the current distribution around electrodes of any shape follow the same mathematical law, namely Laplace's differential equation, the right-hand expression of equation 61 is valid not only for spherical electrodes but for any shape of electrode whether it be a rod, a ring, a disk, or a more complicated form. Therefore, if the resistance is known, which differs with the shape, the continuous current-carrying capacity can be determined easily.

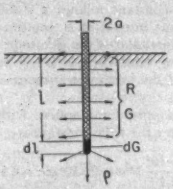


Figure 15. Increment of ground conductance with length of a rod

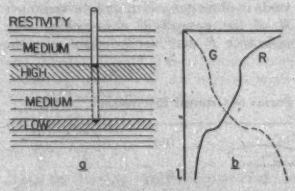


Figure 16. Measurement of rod resistance against depth

The voltage at the ground electrode, measured from the metal to a far distant point is, from the last term of equation 61

$$E=IR=\sqrt{2\rho\lambda\theta} \tag{62}$$

Besides the ground constants E depends only on the temperature rise in the steady state. Conversely, the voltage applied to a ground electrode determines its steady-state temperature. These conclusions are true for any shape of electrode.

As an example, for $\theta=60$ degrees centigrade in moist soil,

$$E=\sqrt{2\cdot 10^2\cdot 1.2\cdot 60}=120 \text{ volts}$$

This voltage must not be surpassed if that temperature rise is not to be exceeded.

The admissible current density at the surface of the ground electrode, where the highest temperature exists, determined for a spherical electrode from equation 61 is

$$i=\frac{I}{4\pi B^2}=\frac{1}{B}\sqrt{2\frac{\lambda}{\rho}\theta} \tag{63}$$

For the former example

$$i=\frac{1}{1\text{m}}\sqrt{2\frac{1.2}{10^2}60}=1.2 \text{ amperes per square meter}$$

Thus the current density permitted for continuous loading of the electrode is fairly small. The soil surrounding the electrode must not heat up to 100 degrees centigrade, since the moisture would then evaporate completely, and the current would be interrupted by the enormously increased resistance.

Short-Time Heating. For short-time loading of the ground electrode the second member of equation 57, the heat-conduction term, plays only a minor role and thus may be neglected. The remaining differential equation then becomes

$$\frac{d\theta}{dt}=\frac{\rho}{\gamma}i^2 \tag{64}$$

The temperature rise thus follows the same law as it does with ordinary linear conductors. If resistivity ρ and specific heat γ are constant, the temperature rise is linear with time, and thus the admissible current density is

$$i=\sqrt{\frac{\gamma}{\rho}\frac{\theta}{t}} \tag{65}$$

Because the length dimension x does not appear in equation 64, this differential equation is true for every volume element of the soil, independent of the pattern of flow of the current. Hence equation 65 is valid for any shape of the ground electrode.

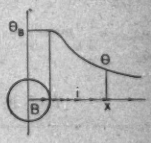


Figure 17. Temperature distribution around a spherical ground electrode

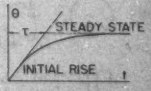


Figure 18. Change with time of ground temperature

For example, an electrode in moist soil and for a temperature rise not exceeding 60 degrees centigrade is permitted to be loaded over a period of 100 seconds by a current density

$$i=\sqrt{\frac{1.75\times10^4}{10^3}\cdot\frac{60}{100}}=100 \text{ amperes per square meter}$$

which is a fairly high value. For sandy soil with ten times higher resistivity a short-time loading at the same current density is permitted for ten seconds only. Higher current density or longer loading period would evaporate the moisture of the soil in a very short time, and an explosion of the space surrounding the electrode might follow, and is sometimes experienced.

The voltage at the electrode with short-time loading may attain a very high value. In the example for moist soil, the voltage is higher than in the steady-state example by the ratio of the current densities, and therefore it reaches here the value

$$E=120\cdot\frac{100}{1.2}=10{,}000 \text{ volts}$$

The initial rise of temperature over a short time as given by equation 64 is shown in Figure 18. The final temperature rise, with fixed constants of the soil, would be given by equation 60, and also is indicated in Figure 18. The intermediate curve follows the complete differential equation 57 but is difficult to derive analytically. However, we can easily determine the time constant τ, defined as the time in which the linear initial rise would reach the steady-state temperature, see Figure 18. For this intersection we have, with use of equations 60 and 64 and substitution in the former the current density for the current

$$\theta_{steady}=\frac{1}{2}\frac{\rho}{\lambda}B^2i^2=\frac{\rho}{\gamma}i^2\tau=\theta_{rise} \qquad (66)$$

Hence the time constant of heating for a spherical ground electrode and its surrounding soil is

$$\tau=\frac{1}{2}\frac{\gamma}{\lambda}B^2 \qquad (67)$$

In addition to the thermal constants of the soil, τ is dependent only on the square of the radius B. For other forms of electrodes the time-constant follows a similar form except that instead of B another characteristic dimension of the electrode must be used, being somewhere between the maximum and the minimum dimension of the electrode.

For example, for a sphere with radius $B=1$ meter the time constant is

$$\tau=\frac{1}{2}\frac{1.75\cdot10^3}{1.2}1^2=0.73\cdot10^3 \text{ sec}=8.5 \text{ days}$$

This is a very long period, due to the very low heat conductivity of the soil, but it is completely in accord with test results.

LINEARLY EXTENDED FIELDS

Buried Long Electrodes. In the foregoing discussions there have been considered only electrodes with constant voltage over their length. However, with the use of long electrodes such as wires or strips, cable sheaths, railroad or tramway tracks, pipe lines, or similar ground electrodes of considerable length, the current may suffer an ohmic drop due to the internal resistance r of the electrode before it spreads out in the resistance R of the ground. Figure 19 shows how the total current I_0 enters a ground wire, follows its length, gradually being attenuated, and leaving the wire as spatial current i. There are measured now the wire current I in amperes, the ground current i in amperes per meter, the resistance r of the electrode in ohms per meter, and the resistance R of the ground in ohm-meters. The resistance R may vary slightly over the length x of the wire due to the concentration of the ground-current density i near the end points. However, taking a mean value over the length is sufficiently accurate for this problem.

According to Kirchhoff's laws, at any point x of the long wire the sum of the inflowing and outflowing current within the wire and the current flowing to ground is zero. On the other hand, the voltage over a narrow rectangle formed by a wire resistance element $r\cdot dx$ and the two adjacent ground resistances R is zero. Therefore

$$\left.\begin{aligned} i+\frac{dI}{dx}&=0\\ R\frac{di}{dx}+rI&=0 \end{aligned}\right\} \qquad (68)$$

from which can be obtained the differential equation, for the wire current I, for example,

$$\frac{d^2I}{dx^2}-\frac{r}{R}I=0 \qquad (69)$$

If we reckon x from the far end of the wire of length l, and write for abbreviation

$$\delta=\sqrt{\frac{r}{R}} \qquad (70)$$

the solution of equation 69 gives the current distribution in the wire as

$$I=\frac{\sinh\delta x}{\sinh\delta l}I_0 \qquad (71)$$

Correspondingly, the ground-current distribution results from the first equation 68 as

$$i=\delta\cdot\frac{\cosh\delta x}{\sinh\delta l}I_0 \qquad (72)$$

The variation of both currents along the length x of the electrode is shown in Figure 19b.

Near the terminal of a long conductor the hyperbolic distributions have a space constant X defined by the subtangent as

$$X=\frac{1}{\delta}=\sqrt{\frac{R}{r}} \qquad (73)$$

If the electrode has a length of more than about $3X$, the ground current will have attenuated to an insignificant remainder over that length. Thus the effect of buried long electrodes is limited by gradual attentuation, determined by the ratio of wire to ground resistance, as seen by equation 73.

For low values of wire resistance r or length l the product δl is small and there is

$$\left.\begin{aligned} \sinh\delta l&\approx\delta l\\ \cosh\delta l&\approx1 \end{aligned}\right\} \qquad (74)$$

Therefore

$$\left.\begin{aligned} I&=\frac{x}{l}I_0\\ i&=I_0/l \end{aligned}\right\} \qquad (75)$$

Table II. Resistance of Simple Forms of Ground Electrodes

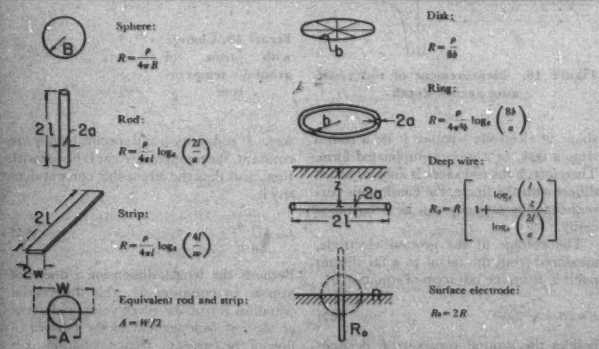


Table III. Geometric Mean Distances for Parallel-Rod Electrodes

n =	Arrangement	Geometric Mean Distance
2		$A=\sqrt{aS}$
3		$A=\sqrt[3]{aS^2}$
4		$A=\sqrt[4]{\sqrt{2}aS^3}$

Table IV. Resistance and Dimensions of Equivalent Ground-Return Conductor

$f=$	50	150	500	5,000	c
$R=$	0.05	0.15	0.5	5	Ω/km
$d=$	2.1	1.3	0.7	0.2	cm
$D=$	800	460	250	80	m

Thus the wire current decreases linearly with x and the ground current is uniformly distributed over l, as is the case with constant-voltage electrodes.

For large values of wire resistance r or length l, excluding, however, the point $x=0$ and its neighborhood, there is

$$\sinh \delta x \approx \cosh \delta x \approx e^{\delta x}/2 \tag{76}$$

Therefore, according to equations 71 and 72, both currents I and i attenuate exponentially from their original values, and the ground current is related to the wire current by

$$i=\sqrt{\frac{r}{R}}I \tag{77}$$

The resistance R_0 of the entire electrode to ground is given by the ratio of voltage E to terminal current I_0, the voltage being equal to the ohmic drop of the initial ground current i_0 across its ground resistance R. Thus

$$R_0=\frac{E}{I_0}=\frac{Ri_0}{I_0} \tag{78}$$

Using equation 72 at the terminal $x=l$, and substituting equation 70, the ground resistance of an extended buried electrode is generally

$$R_0=\sqrt{rR}\cdot\coth \delta l \tag{79}$$

and for large δl, where coth δl becomes 1, is simply

$$R_0=\sqrt{rR} \tag{80}$$

Hence the ground resistance of a long electrode depends equally on the electrode's metallic resistance electrode and the soil's resistance soil, the geometric mean value being effective.

For example, for the lead sheath of a cable of radius $a=2$ centimeters and length $l=1$ kilometer buried in moist soil close to the surface of the earth, the ground resistance of each meter of cable, using equation 30, is

$$R=\frac{\rho}{2\pi}\log_e\left(\frac{l}{a}\right)=\frac{10^3}{2\pi}\log_e\left(\frac{10^3}{2\cdot 10^{-2}}\right)$$
$$=170 \text{ ohm-meters}$$

This would give a total resistance of the lead sheath to ground of $R/l=0.17$ ohm, if the voltage of the electrode were kept constant over the entire length. The resistance of the lead sheath is about $r=1.5\cdot 10^{-3}$ ohms per meter, giving a space constant

$$X=\sqrt{\frac{170}{1.5\cdot 10^{-3}}}=337 \text{ meters}$$

and since coth $1{,}000/337=1$, a resultant resistance of lead sheath and ground

$$R_0=\sqrt{1.5\cdot 10^{-3}\cdot 170}=0.5 \text{ ohm}$$

Hence the voltage on the sheath will decrease over the cable length to nearly zero and the effective resistance R_0 is three times as great as were this voltage constant.

Separate Conductors Buried in the Earth. If cross section and conductance of the electrode are considerable, the currents may be led to much greater distances. Such conductors sometimes play a tricky role, even if they are not directly connected to any electric system. They collect the streamlines of current in one region and carry them into a distant region of the ground.

For a long pipe in an extended ground field, as in Figure 20, an equilibrium is established between the parallel current density i_1 in the ground and i_2 in the pipe extending in the direction of the streamlines. The field strengths e in soil and conductor are the same, and since the current density is field strength over resistivity, the ratio of the current densities in electrode and soil is

$$\frac{i_2}{i_1}=\frac{e_2/\rho_2}{e_1/\rho_1}=\frac{\rho_1}{\rho_2} \tag{81}$$

Thus the current densities are inversely as the resistivities.

For a steel conductor buried in moist ground, there must be expected

$$\frac{i_{steel}}{i_{soil}}=\frac{10^3}{10^{-7}}=10$$

and a still greater ratio if the ground is dry. Therefore a steel pipe of ten square centimeters cross section can collect current from a ground area of

$$10^3\,\frac{10}{10^4}=10^3 \text{ square meters}=1 \text{ square kilometer}$$

of cross section. Hence such a pipe is able to suck ground current from wide areas and carry it to distant points.

For a short pipe in an extended ground field, as in Figure 21, streamlines of current will enter at one end and leave from the other end. The voltage over the length $2l$ of the pipe in the undisturbed ground field is

$$E=2le=2l\rho i \tag{82}$$

This voltage works on the entrance and exit ground resistance of each end of the pipe and produces a current I in the center of the pipe, the metallic resistance being insignificant. Thus, with use of equation 30,

$$E=2RI=\frac{2\rho I}{2\pi l}\log_e\left(\frac{2l}{a}\right) \tag{83}$$

Equating equations 82 and 83 gives a pipe current

$$I=\frac{2\pi l^2}{\log_e\left(\frac{2l}{a}\right)}\,i \tag{84}$$

related to the current density i in the undisturbed underground field and independent of resistivity ρ. If groups of parallel pipes are present instead of a single pipe, their geometric mean distance A rather than the radius a of a single pipe is to be used, see equation 50.

For example, a pipe of half length $l=100$ meters and radius $a=10$ centimeters will collect from a field of current density $i=10^{-4}$ amperes per square meter a maximum current

$$I=\frac{2\pi 100^2}{\log_e\left(\frac{2\cdot 100}{0.1}\right)}\,10^{-4}=0.83 \text{ ampere}$$

Figure 21 shows that with such a pipe the current lines over a circular area are collected, the diameter D of which can be found from

$$I=\frac{\pi}{4}D^2 i=\frac{2\pi l^2}{\log_e\left(\frac{2l}{a}\right)}\,i \tag{85}$$

Thus the diameter of collection is

$$D=2l\sqrt{\frac{2}{\log_e\left(\frac{2l}{a}\right)}}=2l\sqrt{\frac{2}{6\text{–}10}}\approx l \tag{86}$$

if an average value of the logarithm of about 8 is used.

Such pipes may suffer electrolytic corrosion if the d-c density exceeds a value of the order of 0.1 ampere per square meter. The average entrance or exit current density over the surface of the pipe in Figure 21 is

$$\bar{i}=\frac{I}{2\pi al}=\frac{l/a}{\log_e\left(\frac{2l}{a}\right)}\,i \tag{87}$$

showing a high current concentration over the density i in the free field, and this may even be doubled at the pipe ends. For the

example the mean current density along the pipe is

$$i = \frac{100/0.1}{7.6}\, i = 132\, i = 132 \cdot 10^{-4} = 1.32 \cdot 10^{-2}$$ ampere per square meter

which is under the corrosion limit.

For a long pipe passing through a limited ground field, as in Figure 22, the problem of the development of the current lines in space is highly complex. Ollendorf found an approximate solution for the maximum current I_p developed in a pipe of radius a which passes at distance S an electrode from which a current I enters the ground, namely,

$$I_p = \frac{\sinh^{-1}\sqrt{\frac{S}{a}}}{\log_e\left(4\,\frac{S}{a}\right)}\, I \qquad (88)$$

The current collected in this way, as shown by Figure 22, may spread out over vast distances depending on the resistivities of ground and pipe. The maximum surface density of the current entering the pipe, according to Ollendorf's solution, is

$$i = \frac{I}{\pi a S}\,\frac{1}{\log_e\left(4\,\frac{S}{a}\right)} \qquad (89)$$

With current $I = 100$ amperes entering the ground through an electrode at distance $S = 30$ meters from a pipe the current density entering the pipe of radius $a = 10$ centimeters will be

$$i = \frac{100}{\pi \cdot 0.1 \cdot 30}\,\frac{1}{\log_e\left(4\,\frac{30}{0.1}\right)} = 1.5$$ amperes per square meter

a value which will produce severe electrolytic corrosion, if it is direct current.

Alternating Return Current Under Transmission Lines. This article has dealt up to now with the effects of the resistivity of the ground without considering any inductive action of the currents. These derivations are true for direct current flowing through the ground. However, they are equally valid for alternating current as far as the proximity of the electrodes is concerned, for here the inductive action of the changing magnetic fields is negligible compared with the effect of the high resistivity of the ground. Only for extremely rapid change with time this may be modified, as will be shown later.

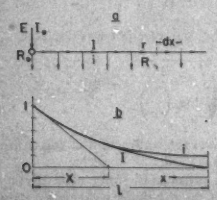


Figure 19. Current distribution along an extended electrode

If ground current flows over a long distance between entrance and exit electrode, the current lines in the d-c case spread out over such a broad transverse area in the earth, as seen by Figure 4a, that the resistance is negligibly small except for the proximity of the electrodes, as previously shown. For alternating current, however, with decreasing effect of the resistance the self-inductive action of the magnetic field becomes preponderant, and thus the distribution of the current lines in the ground under a-c conditions will be determined mainly by the inductive effects. It is well known that the currents in such a case are so distributed that the energy of the magnetic field and thereby the self-inductance tend to become a minimum.

Therefore an alternating return current in the ground under a long transmission line will not spread to a great distance, as direct current does, but will concentrate on paths in proximity to the transmission line, as shown in Figure 23. Hence the distribution of alternating current in the ground is governed by the laws of skin effect, laterally as well as in depth. Because

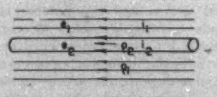


Figure 20. Long pipe embedded in an extended ground field

Figure 21. Short pipe buried in an extended ground field

of the high resistivity of the soil, however, much larger dimensions come into consideration than with metallic conductors.

A single transmission line, as in Figure 23, will develop concentric magnetic lines of force of nearly circular form, at least in the neighborhood of the line, where the magnetic effect of the return current in the ground is of lesser importance because of its low density. Therefore the phenomena will be dependent primarily on the distance y from the center of the wire, carrying the total current I, to the point considered at the earth. The error caused by this assumption is usually small as compared to that caused by subsoil heterogeneity. With angular frequency ω, the differential equation of the distribution over the ground of the current density i then is

$$\frac{1}{y}\,\frac{d}{dy}\left(y\,\frac{di}{dy}\right) - j \cdot 2\pi\mu\,\frac{\omega}{\rho}\,i = 0 \qquad (90)$$

a complex relation similar to that for other skin-effect problems. The value $\mu = 10^{-7}$ is the permeability of nonmagnetic material in the meter-kilogram-second system.

The solution of this equation is given by a Bessel function H_0 of zero order. With abbreviation

$$\kappa = \sqrt{2\pi\mu\,\frac{\omega}{\rho}} \qquad (91)$$

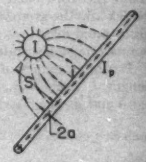
the current density, up to frequencies of about 5,000 cycles per second, is

$$i = \frac{\kappa^2}{2}\, I \cdot H_0(\sqrt{j}\,\kappa y) \qquad (92)$$

where the argument of the Bessel function depending on distance y is complex, indicating that the distribution of the return current through the ground occurs in waves.

For two instants, 90 degrees displaced in time, the values of the Bessel function H_0 are shown in Figure 23, determining the current density against distance. From

Figure 22. Long pipe running through a limited ground field



numerical tables of this Bessel function it can be derived that directly under an overhead power line of height $y = h = 10$ meters the current density at 60 cycles per second in moist soil of $\rho = 10^2$ ohm-meters is nearly

$i = 3 \cdot I$ in amperes per square kilometer

Thus for every ampere of line current there develops a current density of three amperes per square kilometer in the ground under the line, and naturally a still smaller current density at greater distances.

The current density in the ground decreases to an insignificant magnitude at a distance of about $y = 3/\kappa$, as seen by a discussion of the function H_0. Hence for moist soil the zone of extinction is

For current of 60 cycles per second about 2,000 meters,

For current of 500 cycles per second about 700 meters,

and a still smaller distance for higher frequencies. Thus a return current under a transmission line flows only in a moderately broad zone through the ground under and to both sides of the line. This zone follows any trace of the line, it may be straight or curved, since the distribution of the return current always seeks to reduce the self-inductance to a minimum and therefore to avoid any open loop between line current and return path.

The field strength in the ground, with use of equations 91 and 92, is

$$s = pi = \pi\mu\omega l \cdot H_0(\sqrt{j}\,\pi y) \qquad (93)$$

Therefore the voltage over a distance l on the ground surface immediately under the transmission line, namely for $y = h$, is

$$E = \pi\mu\omega l l \cdot H_0(\sqrt{j}\,\pi h) \approx \omega l l \left[\frac{\pi}{2} + j2\log_e\left(\frac{1.12}{\pi h}\right)\right] 10^{-7} \qquad (94)$$

Herein an asymptotic approximation of the Bessel function is used for small values of the complex argument, resulting in a form which has distinct real and imaginary components. The voltage over the ground, therefore, is complex, consisting of two perpendicular vector components, where

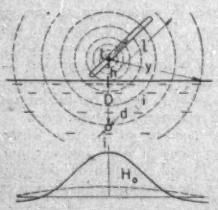


Figure 23. Distribution of ground-return currents under a-c transmission lines

the real part gives the effective resistance of the return current

$$R = \frac{\pi}{2}\mu\omega l = \pi^2 f l \cdot 10^{-7} \qquad (95)$$

while the imaginary part determines the effective self-inductance

$$L = 2l \cdot \log_e\left(\frac{0.178}{h}\sqrt{\frac{\rho}{f}}\right) \cdot 10^{-7} \qquad (96)$$

In the last two equations the frequency f per second is used instead of the angular frequency ω.

Hence alternating return current through the ground experiences a resistance which is proportional to length l and to frequency f but independent of resistivity ρ of the soil. Table IV gives the return resistance R in ohms per kilometer for various frequencies in moist soil of $\rho = 10^2$ ohm-meters. The values are not unimportant for heavier currents or for frequencies above the power range. The same return resistance would be attained by a fictitious copper wire of an equivalent diameter d as given in the third line of Table IV.

The self-inductance of the return currents as given by equation 96 is also proportional to length l, depends slightly on the height h of the transmission line and, to an even lesser degree, on resistivity and frequency, these being under the logarithm of a square root. Thus for a large range of such data the self-inductance is very nearly

$L = 0.9$ millihenry per kilometer

or

$\omega L = 0.34$ ohm per kilometer

This self-inductance of the ground current adds to the self-inductance of the line current, which is also determined by a well-known logarithmic relation. So is also the self-inductance of a fictitious return conductor of diameter d and depth D under the surface, the ohmic and inductive effects of which may be taken equivalent to those of the ground return. By comparison of equation 96 with the self-inductance of such an ideal return system, the equivalent depth can be determined. We see from the last two lines in Table IV that the equivalent diameter d of a copper return wire would be of the order of two centimeters for 50 cycles per second but of only 0.2 centimeters for 5,000 cycles per second. On the other hand, the equivalent depth D would vary from 800 meters to 80 meters over the same frequency range.

Inductive Interference of Parallel Lines. If at a distance y a neighboring line runs parallel to the transmission line with current I returning through the ground, as shown in Figure 24, and the two ends of the secondary line are directly or indirectly grounded, then a voltage develops over a length l of this line according to equation 93

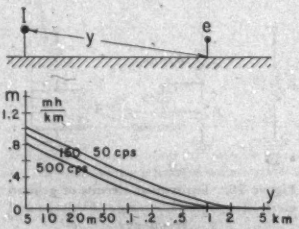


Figure 24. Mutual inductance between lines with ground return

$$E = \pi\mu\omega l l \cdot H_0(\sqrt{j}\,\pi y) \qquad (97)$$

This is a voltage of mutual effect between primary and secondary line caused mainly by action of the ground-return currents and their magnetic field.

Hence the coefficient of mutual induction for the unit length of both lines is

$$m = \pi \cdot H_0(\sqrt{j}\,\pi y) \cdot 10^{-7} \qquad (98)$$

Since the value of the Bessel function H_0 is complex, this mutual inductance has amplitude and phase angle in contrast to the straight inductance of two linear circuits alone. This is effected by the alternating currents produced in a spatially extended third conductor, namely, the ground. Figure 24 shows the amplitude of the mutual inductance in millihenrys per kilometer dependent on distance y between primary and secondary circuit for various frequencies, if the resistivity of the intermediate ground is $\rho = 10^2$ ohm-meters, as for moist soil. In all practical cases the resistivity will not be uniform over surface and depth of the ground between and around such transmission lines, and thus an average resistivity of the entire field should be taken into account. High resistivity of the underground increases the action to a greater distance.

If, for example, a short-circuit current $I = 500$ amperes in a power line flows through an arcing ground to earth and returns through it to the grounded neutral of the power station, then, according to equation 97, a telephone line at a distance $y = 1$ kilometer, running parallel to the power line over a length $l = 10$ kilometers and using the ground for return, will suffer a voltage of

$$E = \pi \cdot 10^{-7} \cdot 377 \cdot 500 \cdot 10 \cdot 10^3 \cdot 0.20 = 118 \text{ volts}$$

a value which would annihilate any telephone conversation.

IMPULSE CHARACTERISTICS

Performance of Driven Rods. It may be asked how closely the current in an electrode and the surrounding ground can follow a rapid variation of the voltage. The best criterion for this is given by the values of the electric time-constants and the natural periods of oscillation.

In Figure 25 the current I impinges on the rod electrode and enters the ground,

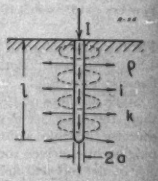


Figure 25. Impulse current spreading from driven rod

which in addition to its resistivity has a dielectric constant k. Thus in parallel to the conductive current in the ground there develops a capacitive or displacement current in case the electrode voltage changes with time. The displacement current follows exactly the lines of the conductive current, and thus the ground electrode will have a capacitance, as reciprocal to the resistance of equation 30,

$$C = \frac{kl}{2 \cdot \log_e\left(\frac{2l}{a}\right)} \cdot \frac{10^{-9}}{9} \text{ farad} \qquad (99)$$

The currents in electrode and ground, furthermore, form a magnetic field indicated by the dashed lines in Figure 25.

This field is highest where the current is most concentrated, namely around the rod electrode. Therefore the inductance of the ground currents is mainly given by the distribution of the currents in the rod, having full value at the top and decreasing to zero at the bottom. The inductance of such a rod is

$$L = 2l \cdot \log_e\left(\frac{2l}{a}\right) \cdot 10^{-7} \text{ henry} \qquad (100)$$

The capacitive time constant of any circuit element is given by the product of capacitance and resistance, and thus a rod electrode has a time constant

$$\tau_C = CR = \frac{\rho k}{4\pi \cdot 9 \cdot 10^9} \qquad (101)$$

It depends only on resistivity and dielectric constant k, the value of which for ordinary soil may be of the order of 9, in view of the high value for water.

For example, for moist soil

$$\tau_C = \frac{10^2 \cdot 9}{4\pi \cdot 9 \cdot 10^9} = 8 \cdot 10^{-9} \text{ second}$$

which is an extremely small value. For rock as underground the value is about $8 \cdot 10^{-7}$ second.

The inductive time constant as quotient of self-inductance and resistance is

$$\tau_L = \frac{L}{R} = 4\pi \frac{l^2}{\rho} \cdot 10^{-7} \qquad (102)$$

It is proportional to the square of the length l of the electrode, and therefore greatly dependent on this dimension. For example, for a rod of $l = 6$ meters in moist soil

$$\tau_L = 4\pi \frac{6^2}{10^2} \cdot 10^{-7} = 4.5 \cdot 10^{-7} \text{ second}$$

For the same electrode in rock the value is $4.5 \cdot 10^{-9}$ second. Both these values are likewise very small.

Since all these numerical values are less than the time usually assumed for the shortest possible lightning impulse impinging on a driven rod, current and voltage in the rod will follow such impressed impulse of the order of 10^{-6} seconds without any significant time delay and will behave as in the steady state. Hence capacitance and inductance of a driven rod of moderate length play no significant part even with rapid lightning phenomena.

The natural oscillations of which such a rod is capable have a period

$$T = 2\pi\sqrt{LC} = \frac{2\pi\sqrt{k}}{3 \cdot 10^8} \cdot l \qquad (103)$$

depending only on dielectric constant and length. For the same example, the natural period is

$$T = \frac{2\pi\sqrt{9}}{3 \cdot 10^8} \cdot 6 = 3.8 \cdot 10^{-7} \text{ seconds}$$

This also is beyond the duration usually assumed for lightning strokes, and indicates the frequency up to which the rod behaves as an ohmic resistance.

The damping of the free oscillations is determined by the value of the quotient of resistance and surge impedance in comparison to the value one half, namely,

$$\frac{R}{\sqrt{L/C}} = \frac{\rho\sqrt{k}}{120\pi l} \begin{cases} > 1/2 \text{ periodic} \\ < 1/2 \text{ aperiodic} \end{cases} \qquad (104)$$

For the same rod in moist soil

$$\frac{R}{\sqrt{L/C}} = \frac{10^2\sqrt{9}}{120\pi \cdot 6} = \frac{1}{7.5}$$

so that any natural oscillation would be aperiodically damped. For rock, however, the quotient assumes the value 13, indicating that here the driven rod can oscillate periodically.

An equivalent diagram is often convenient to represent the properties of a circuit element in a simplified form. In view of the foregoing numerical values there is no doubt that for low frequencies a driven rod and all its derived electrodes can be represented by a lumped resistance, as in Figure 26a. This remains true for a ground electrode of moderate length up to high and even very high frequencies. However, it should be noticed that a

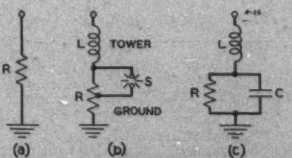


Figure 26. Equivalent circuits of ground electrodes over wide range of voltage and frequency

(*a*). *Low voltage, low frequency*
(*b*). *High voltage, high frequency*
(*c*). *Ultrahigh frequency*

tower, or a lead, through which a lightning discharge reaches the electrode may have considerable self-inductance because of its height. This is indicated in Figure 26b. If the voltage at the rod electrode is very high, as is frequently the case with lightning discharges, the field strength at the rod becomes so great that the electric strength of the ground is broken down and sparks discharge from the rod into the neighboring ground thereby considerably decreasing the entire ground resistance. This performance is indicated in the equivalent diagram of Figure 26b by a spark by-pass to a part of the ground resistance.

If the discharge to the ground electrode is extremely rapid or the equivalent frequency is extremely high, of an order of more than 10^6 cycles per second, a considerable displacement current in the capacitance of the ground will parallel the conductive current in the resistance, and together with the self-inductance of both of these currents through the rod, will effect an equivalent diagram as in Figure 26c. The time-constants, the natural oscillations, and the damping of the electrode, as in equations 101 to 104, now will be determinative.

Performance of Buried Wires. In ground electrodes of considerable length, as with buried long wires, the self-inductance will play a larger part with respect to impulse currents, since the inductive time constant, see equation 102, increases as the square of the length. The capacitive effect of the ground, see equation 101, will not change, however, and may be neglected. Since buried wires usually have substantial cross section, the internal resistance of the electrode also may be neglected in comparison to the self-inductance. Figure 27a shows the remaining data of the problem, namely, the wire current I in amperes, the ground current i in amperes per meter, the self-inductance L of the wire in henrys per meter, and the ground resistance R in ohm-meters.

Corresponding to the case where the wire resistance is taken into account, see Figure 18 and equation 68, the relations between the currents in the present example are

$$\left.\begin{aligned} i + \frac{dI}{dx} &= 0 \\ R\frac{di}{dx} + L\frac{dI}{dt} &= 0 \end{aligned}\right\} \qquad (105)$$

Their combination gives the differential equation for the current in the wire

$$\frac{d^2I}{dx^2} - \frac{L}{R}\frac{dI}{dt} = 0 \qquad (106)$$

and a corresponding equation for the ground current i. Equation 106 is the well-known differential equation of heat diffusion. A solution for a short impulse is

$$I = \frac{K}{\sqrt{t}} \epsilon^{-\frac{L}{R}\frac{x^2}{t}} \qquad (107)$$

where the amplitude is still free as determined by a constant K of integration, while the exponent depends, in addition to L and R, on the square of distance x and on time t. This function is plotted in Figure 27b against distance x and in Figure 28a against time t. Equation 107 represents an impulse curve over the time axis, which increases at first slowly and then steeply, reaches a maximum peak, and decreases gradually toward zero. Such a curve might well be used to approximate the time characteristic of a lightning discharge to ground which is known from many experimental investigations.

Figure 27b shows the manner in which the current in the wire, from a narrow zone in the beginning, spreads gradually

over the length of the wire. It is not necessary to identify the origins of x and of t in equation 107 with the origin of the lightning current. Figures 27 and 28 show that displacements in space x_0 and in time t_0 can be used for constants of the solution (107) and by proper selection of these every actual case can be approximated closely.

The points at which the spatial curves of Figure 27b are steepest determine the front zone of the attenuated propagating wave of current. Their location can be derived from equation 107 and is given by

$$\frac{L}{R}\frac{x^2}{t}=\frac{1}{2} \tag{108}$$

These points travel with a velocity

$$v=\frac{dx}{dt}=\frac{1}{4}\frac{R/L}{x}=\frac{10^9}{4\pi}\frac{\rho}{x} \tag{109}$$

where R/L is taken from equation 102, both data, however, being here related to the unit length. Hence the velocity of the front is not constant but decreases rapidly with distance x.

Buried long wires are often used as electric counterpoises additional to the tower footing conductance of high-voltage transmission lines, in case the resistivity of the soil is so high that it is difficult otherwise to obtain a low ground resistance. With a resistivity, therefore, of $\rho=10^3$ ohm-meters, the front velocity of the current wave will be, for example, at distance $x=10$ meters on the wire,

$$v=\frac{10^9}{4\pi}\frac{10^3}{10}=0.8\cdot10^8 \text{ meters per second}$$

This is about one-fourth the velocity of light, a velocity reached in straight conductors in air. In ground wires of considerable length, therefore, the joint effect of self-inductance and ground resistance leads to a lower and ever decreasing wave velocity.

The voltage at every point of the wire is determined by the ohmic drop of the ground current i in the ground resistance R. By using the first equation 105 and differentiating equation 107, the voltage is

$$E=Ri=-R\frac{dI}{dx}=2L\frac{x}{t}I \tag{110}$$

whereby E is reduced for every distance and time to equation 107 for the current I. Since E is proportional to I, a definite value of the impedance is obtained, which, however, is dependent on distance and time. The surge impedance is

$$Z=\frac{E}{I}=2L\frac{x}{t} \tag{111}$$

and is proportional to the self-inductance L per unit length of the wire. For any point x of the wire, Z is inversely proportional to time.

There may be correlated to the beginning of the steep ascent of the current with time, as shown by t_0 in Figure 28a, a location x_0 corresponding to about half the value of equation 108, so that

$$\frac{x_0^2}{t_0}=\frac{1}{4}\frac{R}{L} \tag{112}$$

By substitution of this value of x in equation 111 and use for R and L of values per unit length derived from equations 30 and 100 for a finite wire, the surge impedance for the terminal of the wire becomes

$$Z_0=\frac{t_0}{t}\sqrt{\frac{RL}{t_0}}=\frac{t_0}{t}\sqrt{\frac{2\rho\cdot10^{-7}}{\pi t_0}}\log_e\left(\frac{2l}{a}\right) \tag{113}$$

Since buried wires usually are embedded near the surface of the ground, extending to both sides from the terminal, the value of equation 30 is doubled for the resistance here in question.

We consider for an example a wire of length $l=75$ meters and of radius $a=0.5$ centimeter, buried in ground of high resistivity $\rho=10^3$ ohm-meter, and we estimate the time until the steep ascent of the

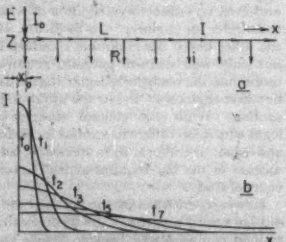


Figure 27. Distribution of impulse current along a buried wire

lightning current occurs as $t_0=0.2\cdot10^{-6}$ second. Then the surge impedance for the practical start of the current at $t=t_0$ will be

$$Z_0=\sqrt{\frac{2\cdot10^3\cdot10^{-7}}{\pi\cdot0.2\cdot10^{-6}}}\log_e\left(\frac{2\cdot75}{0.5\cdot10^{-2}}\right)=184 \text{ ohms}$$

and this value decreases hyperbolically with increasing time as shown in Figure 28b.

The impedance would decrease gradually to zero, see equation 113, due to the omission of ohmic resistance of the infinite wire in this calculation. Actually the impedance cannot drop lower than the d-c ground resistance of the finite buried wire, which in this example is

$$R_0=\frac{10^3}{\pi\cdot75}\log_e(3\cdot10^4)=44 \text{ ohms}$$

thus limiting the decrease of Z, as shown in Figure 28b by the dashed line.

CONCLUSION

By using for the development of the current distribution in the ground such mathematical analyses as are best suited to each special problem, rather than any general method of rigorous calculation, the treatment does not depart far from the physical aspect, and the solutions become fairly simple and easy to survey, even in complicated examples. In view of the great heterogeneity of the ground under the surface of the earth, the effect of which can never be taken into account

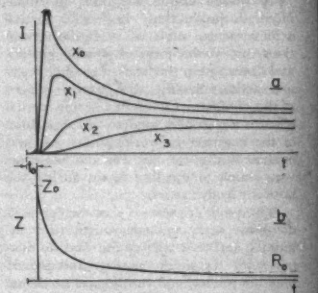


Figure 28. Change with time of current and surge impedance in buried wires

by any rigorous deduction, such a simplified foundation of the principles of ground currents appears appropriate from the viewpoint of engineering as well as from the viewpoint of the economic use of science.

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The Engineer and His Future

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PRESIDENT AIEE

Representation of the engineer in civic and state affairs and promulgation of measures to improve his economic status by means of an overriding association of engineers are suggested by President Powel in this article.

WAR is a tremendous stimulant. It brings about not only enormous physical production, but also mental achievements, such as scientific inventions, art in the form of stirring posters, and literature in the form of moving books and articles dealing with various phases of the conflict. One result of this mental effort is a searching analysis of the position of the engineer in world affairs. It was evident during the last war and has come very much to the fore again during the last four or five years.

A frequent criticism is that the engineer does not carry enough weight in community and civic affairs and that he does not enjoy the public prestige and regard that his professional brothers in medicine and law enjoy. Another is that his occupation is not as continuous and secure as it should be. This is true particularly of civil and construction engineers. Another is that his remuneration is not as high as in other professions.

Whether these criticisms are well founded or not will remain pretty much a matter of opinion. It is impossible to establish the facts in the matter, because one can set up premises and definitions to prove one's case, just as in the present controversy regarding the increase in the cost of living one can prove anything from 10 to 100 per cent, depending upon what is included in the cost of living.

Nevertheless, because one cannot expect an exact answer may not be sufficient cause for ignoring the subject.

That the engineer in the early days did not get much public esteem is explained by the fact that most of them were essentially practical men with little theoretical training, whereas the physician, the lawyer, and the pastor were all university trained. The relatively few scientists who devoted themselves to technical developments never came in direct contact with the public, as did doctors and lawyers, and their work was consequently not appreciated outside of their own small circle. Up to the beginning of this century, theoretical training in an engineer was looked on by old timers with suspicion as likely to lead to errors in design and performance, particularly because the application of theory invariably led to marked savings in materials, which was tantamount, they argued, to removal of the margins of safety. The older professions likewise did not give the college-trained engineers a warm welcome, and attempted to establish a difference by referring to the "technical professions" as distinct from the "learned professions." The difference is real and engineers must recognize it. Today there is still no minimum standard requirement for the practice of engineering and even no satisfactory definition of what constitutes an engineer. In medicine, on the other hand, the minimum standard is not only well defined but also requires more than the bachelor's degree that satisfies most engineers. In law the situation is similar. While the general scheme of legal education differs in various localities and is not as uniform as in medicine, admission to the bar requires at least seven years of study.

However, criticism by the old die-hards did not retard progress of the theoretically trained engineer who became firmly entrenched in all branches of engineering to the exclusion of the rule-of-thumb type of man.

As the profession developed, more and more of these intellectuals began to realize that while scientific knowledge and engineering achievement were shaping the world and establishing the habits of thought and life, the engineer got scant recognition in the councils of government. Attempts were made to remedy this situation, notably by the establishment during the last war of Engineering Council. This association was formed under a broad charter of what is now the United Engineering Trustees to provide for closer cooperation among the four Founder Societies on matters of general interest to engineers and to the public, and to serve as an agency for united action upon questions of common concern to engineers.

In 1920 it was enlarged to include a much larger group of engineering societies and the name changed to Federated American Engineering Societies. A joint committee drafted the principles for a nation-wide engineering organization to be composed of representatives of local, state, regional, and national societies. The conference met in Washington with 132 delegates representing 66 societies having a total membership of 130,000. After an intensive debate, a constitution was adopted containing the following objective: "To further the interests of the public through the use of technical knowledge and engineering experience, and to consider and act upon matters common to the engineering and allied technical professions."

In 1924 the name of the organization was changed to American Engineering Council and it functioned until the end of 1940 when it went out of existence due to lack of interest and lack of funds.

We need such an overriding engineering society as American Engineering Council that can speak for all engineers with some authority. Legislation of vital importance to industry is enacted but much of it shows no evidence that industry was ever consulted. Even the soundness of such a fundamental law as the Sherman antitrust law can be debated. Unrestricted competition does not necessarily produce the best results. We recognize this when dealing internationally by putting up tariff barriers to keep out those who can undersell us, but we close our eyes to it in our national affairs. In industries where the prices and wages are the same for all, those concerns are the most prosperous and successful that work with the highest efficiency.

Serious attacks are made on our patent system and on organized research for their alleged contribution to antisocial monopoly. Some of our socialist friends would have the product of organized research, both industrial and academic, become common property. In other words, they propose to kill the very thing that has put us in a leading position in scientific progress and has made possible our tremendous contribution to the winning of the war.

Tax policies and legislation are already such as to penalize thrift and make difficult financial protection against business recessions. These are all problems in which the engineer should interest himself because the engineer more than anyone else is shaping our present civilization. It was hoped that he would be able to express himself effectively through American Engineering Council, but that organization died for lack of support chiefly, I think, because it had insufficient contact with the rank and file of engineers, to most of whom it was totally unknown.

Engineering councils on a smaller scale are numerous throughout the United States in the form of local engineering organizations comprising all classes of engineers. Unlike American Engineering Council, they provide support of the engineering profession at the base of the pyramid, so to speak, instead of at the apex. They substitute a large cross-section of

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opinion for a small one. These councils should be encouraged, expanded, and also co-ordinated. They should include among their committees one made up of the most competent men in the district to follow legislation affecting industry and science to relay to the membership any steps by the governing bodies that adversely affect their interests. The individual members through letters to their representatives could then take appropriate action, if they so desired. The better these local associations are financed, the more effective they can become. One of the difficulties is that too many engineers fail to realize that the money they devote to such societies comes back to them many fold in benefits affecting the whole profession. Note the contrast of attitude in this regard between engineers and members of the big labor unions, whose individual incomes are probably lower but who, nevertheless, pay relatively high dues.

A more recent manifestation among engineers is a movement to band together in some form of collective bargaining to improve their personal fortune. Several reasons are advanced for this—one goes back to the depression of the early 30's when many engineers, capable as well as the incapable, could not find employment. This memory lingers and now that they have jobs and the future appears uncertain, they propose to set up machinery through collective bargaining to insure employment. A second reason is that under existing laws many engineers find themselves subject to more-or-less compulsory enlistment in labor unions not to their liking. So they would seek protection by creating an agency of their own. A third reason is the influence of arguments of the so-called white-collar unions that, while wage earners are getting fat pay envelopes through overtime payments and incentive bonuses and such schemes, salaries are fixed and can be improved only through collective bargaining.

None of these arguments can be dismissed as inconsequential. Certainly the young engineer is more practical as regards his personal affairs than were the engineers of past generations. We older men were much more lured by the romance of engineering. The joy of achievement, of new developments, of new solutions of all kinds of problems, were more important and gave us more satisfaction than a few dollars more or less in our pay envelope. Not until we thought of marrying did we discover we had no money. The romance of engineering is not dead, but neither is it any reason to discourage the practical attitude of the engineer. There is, however, a big question as to the best form of collective bargaining for the engineer. Should he form a union of his own or should he join one of the big labor unions organized for a totally different type of person with a totally different process of reasoning and a totally different function in society?

It may be entertaining and instructive to review the origin of those unions. The first union was no doubt founded by a few prehistoric men who discovered that their chances of remaining alive were much improved by banding together against their four-footed enemies. This type of union, of course, endured in the form of villages, cities, districts, countries, empires, and we hope, eventually will develop into one world-wide peaceful union of nations.

As men became skillful with their hands, another type of union, known as the guild, developed which had for its purpose the protection of artisans and other industrial classes. Guilds seem to have been formed first in China and India and introduced into Europe in the eighth century. The first English guilds were formed in the ninth century. These guilds were the forerunners of our technical societies and to some extent our modern labor unions. In the days of the guilds, the artisan was a capitalist to the extent that he owned the tools and other requirements of his trade. The introduction of machinery brought about the factory system with a large demand for capital and labor far beyond anything the guilds had had to deal with.

Labor laws go back in England for hundreds of years. Between 1345 and 1348 the great plague struck Europe, originating in Asia Minor and traveling west to reach England in 1348. The German historian Hecker estimates that 25 million people died, including nearly half the population of England. The result was a serious shortage of labor and wages went sky high. In 1351 to cope with this increase a law was passed known as the "Statute of Laborers" to fix wages and hours of labor at the preplague level. A section in the law was entitled "Victuals shall be sold at reasonable prices." In other words, it was an attempt to keep down the cost of living, which reminds us, of course, of our present Office of Price Administration. The workers did not accept this law without protest. One Walter Halderly in Suffolk was arrested because "he took eight pence a day at reaping time and at the same time made various congregations of laborers and counseled them not to take less than eight pence." He was the labor leader of his day and they put him in jail. But he had some success and after a time a union, or as they were originally called, a "combination," was formed known as the "Great Society," which forced some concessions from the king.

In 1562 labor succeeded in getting through Parliament a "Statute of Artificers" to curb employers who were cheating by paying only apprentice wages. The law forbade a man to employ more than three apprentices for each journeyman on his payroll, and is of interest as being probably the first law enacted with the idea of protecting labor. Most of the early laws were aimed to restrict labor and not to help it. Despite this, combinations of workmen were formed. Among them were silk weavers, basket makers, printers, shipwrights, shoemakers, carpenters, and bricklayers—names which are still familiar to us today. By strikes and by political means, these combinations kept on fighting for the betterment of conditions for the laboring classes, and finally, thanks principally to the efforts of a member of Parliament named Joseph Hume, they succeeded in 1824 in having a royal commission formed to investigate the whole situation. This resulted in 1825 in the repeal of all the previous statutes against combinations of workmen enacted during the preceding five centuries, and, a few years later, in the creation of the "Grand National Consolidated Trade Union," which was probably the first of the trade unions as we know them today. This huge combination of trades at its zenith comprised a million workers, an enormous membership for that period. However, because of internal strife, strikes, and lockouts, it finally broke up and in the middle of the century a fresh start was made with several smaller unions.

In Germany no unions exist. Trade unionism is possible only under a democratic form of government. Labor was always more government controlled in Germany than in other countries, but the revolution of 1918 did bring the German worker independence with collective bargaining and labor arbitration. The economic calamities, which may or may not have been purposely instigated, and the tendency of German labor toward communism, made possible the rise of Hitler. In May 1933 he ordered all unions abolished and their property seized. The union leaders were jailed. Labor was reformed into one government-controlled organization called the "German Labor Front" with Robert Ley as its head. To make it more palatable, employers and professional men were allowed to join. The organization was well dressed up, but the employer was the labor "leader" and the workmen were the "followers." The leader decided everything, but if there was too much complaining, there was recourse to "labor courts"—which meant the local Nazi "gauleiters."

The major purpose of the "labor front" was to inculcate the Nazi doctrine into the members. Even their recreation was supervised through a "strength through joy" department. As in Japan, the burden of government fell unduly hard on the worker and small farmer. In 1933 at the depth of depression the Nazis froze wages at their lowest level. The disparity between the incomes of the poor and the rich became greater in favor of the rich, which is rather an anomaly for a government calling itself "socialist." Another peculiarity of the Hitler brand of socialism, which is contrary to most socialistic ideas, is that he did not have much use for small corporations, which are difficult to control. Consequently, small corporations in 1934 were ordered to combine to a minimum capital of 500,000 marks. Any concern smaller

than this had to be a private business with the individual owner solely responsible.

The history of the labor movement in the United States is, as might be expected, different from that in other countries in view of its development. It was founded by men whose only gospel was free enterprise, even though they probably never had heard of the word. They came over here to better their lot and they had the courage to gamble. The goal was individual opportunity. The reward for taking risks had no limit. The greater the effort, the greater the reward. They found themselves in a country with tremendous opportunities and no labor. The first settlers were the Spanish conquistadores, a hardy crowd of toughs who came over for no other purpose than to spend the rest of their lives in luxury at the expense of the natives. They and their successors had a notorious aversion to work and they exploited the Central American Indians to the point where the Spanish Government had to step in for fear that this source of labor might be wiped out entirely. Incidentally, it is interesting to note that no one succeeded in enslaving the North American Indian. Our good Puritan forefathers in New England, having left Europe to enjoy freedom of thought, freedom of religion, freedom of action, did not indulge in slavery, but they were not above using indentured servants shipped over from England under some flimsy excuse of criminality or with no excuse at all. In 1670 a man and woman in England were fined one shilling each for kidnapping a young girl to ship over to New England. Had they each stolen a shilling they probably would have been hanged. Life was cheap.

In colonial days competition was keen for what labor was available. As far back as 1634 Massachusetts found it necessary to set up a board of three men in each town authorized to fix wages. The general idea was to keep wages down rather than boost them, but, nevertheless, it is interesting as being probably the first legal provision for arbitration in labor disputes.

However, a nation cannot remain forever made up of rugged individualists. Local opportunities decrease, the children and grandchildren are not so rugged, immigrants encouraged to come in as laborers are disillusioned, and the factory system inevitably establishes a class whose only recourse is the sale of their labor to others. These people were exploited just as in other countries—perhaps for a longer period because expanding frontiers and individual opportunities persisted much longer here than elsewhere and retarded collective action on the part of labor. There was also the added complication of diversity of action in individual states. And so, while America's first labor law was enacted in 1813, it was 100 years later that the World War I and the Clayton Act, exempting unions from the stipulations of the Sherman antitrust law, gave labor its opportunity of real development. The Wilson administration insisted that the war industries cease interfering with the organization of their employees and the first collective-bargaining agreement in this country was signed by Newton D. Baker, Secretary of War, and Samuel Gompers of the American Federation of Labor covering construction of camps and cantonments.

Labor unions are a necessary part of our economy. Looking over the picture as a whole, they have been beneficial. It is certain that without joint action on the part of labor our present standard of living could not have been attained. But the question properly may be raised whether the engineer belongs in the type of union just discussed? Does what he has to sell differ from what the machinist has to sell? There is certainly a difference. The machinist, the janitor, the shipping clerk, all have a set task previously laid out for them to do within the limits of their ability. The engineer on the other hand uses his intellect to do something new or different. His training has developed his creative instinct and he takes pride in accomplishment. His work has no monotony unless he wills it so, whereas a man operating an automatic screw machine has little opportunity for self-expression in his work. The engineer's work is not adapted to control by any ordinary time-study procedure nor are the scheduled hours of work likely to be rigidly adhered to. He is much more likely to become an individualist than a man working with a group in the shop. Nevertheless, the engineer has the same instincts of self-preservation as other people and it is natural that he should seek protection through some scheme of collective action. There is nothing wrong with the basic idea. There are all kinds of groups of professional people banded together for mutual assistance. But, how best to attain the desired result is something else again.

Two general schemes have been tried—one by the American Society of Civil Engineers which has authorized its sections to set up collective-bargaining units, and a second scheme prevalent in some plants where the engineers have simply been included in the general "white-collar" union.

In a few cases groups of engineers in a plant or on a project have been able to secure designation as collective-bargaining units; sometimes before a broad over-all unit has been certified, and sometimes breaking out of an already established and certified local bargaining unit.

I have been asked if the Institute should not adopt some such scheme as the civil engineers. The answer is that the Institute has a committee jointly with other technical societies to investigate the whole subject. I do not know what their report will bring forth, but I can state that their preliminary study brings out the difficulties of trying to make collective-bargaining units out of our Institute Sections.

The idea of including engineers in some general white-collar union at first glance looks attractive but in practice it also has its disadvantages. In any concern, no matter what size, the ratio of engineers to draftsmen, clerks, accountants, and so forth, is bound to be quite small, and one runs into the same comparisons as with manual workers. The problems of the majority of clerks are much more akin those of the shopmen than those of the engineer. The engineer, in my opinion, is just as much out of place in the white-collar union as he would be in any shop union, because he is subjected to decisions and rules that are clearly intended for a great majority of men doing an entirely different class of work.

Neither of these schemes, it seems to me, is the answer to the problem if engineering is to remain a profession and not degenerate into a trade. It is not enough to say that belonging to a union for a time is a useful part of a young man's training. Most engineers never get into the supervisory ranks and, therefore, would remain in the union for an indefinite period. Moreover, the seniority processes of unions are liable to be a handicap rather than an advantage to a young engineer's promotion apart from engendering a tendency to lose initiative.

My present opinion, which may be changed later as the result of the findings and recommendations of the aforementioned committee, is that I question if a bargaining agency in the ordinary sense of the term is necessary or desirable for engineers and the protection they rightly seek probably could be provided more effectively by an overriding association embracing all engineers, devoted specifically to the welfare of the profession as a whole and the individual members comprising it. Such an overriding society by the weight of its opinion could help the individual in cases of gross injustice, which is the only type of protection he needs. The types of grievances one encounters with labor unions are not ones likely to concern the engineer. The minor differences of opinion that arise in the course of his work are more likely to be such that they can be settled directly with management.

An overriding association, such as the one suggested, must be entirely independent of our technical societies which have a very definite, important, and growing field of activity. It cannot be set up as a side line of the Founder Societies. It involves real money.

I believe our need is for some overriding association of engineers whose purpose is to represent all branches of the profession in civic and state affairs and which also is capable of watching over the welfare of its individual members in broad issues. It must first set up a definition of what constitutes an engineer, and it must have constant and intimate contact with its local branches to keep the rank and file of engineers informed and interested.

Lighting of Budd Field

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THE BUDD ASSEMBLY PLANT at Bustleton, Pa., known as Budd Field, designed and built for the production of a cargo airplane fabricated of stainless steel, is constructed entirely of steel-reinforced concrete covering nearly 25 acres (Figure 1). The entire assembly area, nearly 600 feet wide and 1,800 feet long, is all on one floor. In plan the area consists of two sections each approximately 135 by 1,800 feet (designated high bays) and six sections each approximately 50 by 1,800 feet (designated low bays).

Each bay has a vaulted roof (Figure 3) made up of a compound curve which gives an appearance of a somewhat flattened section of a cylinder with a ceiling of smooth concrete. In the high bays the roof is supported by columns approximately seven feet by two feet six inches. In the low bays the supporting columns are two feet three inches by three feet. All columns are regularly spaced along the longitudinal element on 40-foot centers. Except for these supporting members there is almost no other structural interference in the entire building.

The vaulted ceilings have no beams or other obstructions with the exception of two rows of skylights in the large bays and one row of skylights in the small bays, together with suspension rods to support craneways and a monorail system throughout the entire plant. In the high bays, the maximum height to the zenith of the arch is 58 feet with a minimum mounting height for lighting equipment of 41 feet above floor level required for clearance of the conveyer systems. In the low bays the maximum height to the zenith of the arch is 33 feet with a minimum mounting height for lighting equipment of 23 feet six inches.

The illumination problem was to provide not less than 35 foot-candles and to design a lighting system which would meet the requirements from an engineering basis and at the same time be reasonable from a cost consideration. In attempting to solve the lighting problem the first subject reviewed was that of suitable light source. Of those commercially available the three which were given consideration were:

1. Incandescent.
2. Mercury.
3. Fluorescent.

The indirect lighting by mercury-vapor lamps of a plant 25 acres in area and nearly 60 feet high is of interest to all illumination engineers. How a lighting system was designed which would meet the requirements from an engineering basis and at the same time be practical from a cost consideration is explained by two engineers who were concerned with the lighting of Budd Field.

An analysis was made of the pertinent data relating to each of the sources considered. It was logical that the high efficiencies of fluorescent and mercury-vapor lamps should gain favorable attention. The longer life of these two types of sources held real significance from a maintenance angle.

The question of relative color values was raised. Tests have shown that different color qualities of equal foot-candles of illumination have little effect on actual visibility. However, color does have a psychological effect that is worth considering. A light that is strong in blue or green is said to have a cool color, and many workers prefer it for certain visual tasks. Mercury lamps, or a combination of mercury and incandescent lamps, or fluorescent lamps produce such a cool quality. Sources strong in orange and red produce a warm color, the most common example being the filament lamp.

Fluorescent and mercury showed approximately equal merit on the basis of this preliminary analysis. However, the small amount of visible radiation from a single unit of the largest fluorescent lamp available indicated the necessity of installing tremendous numbers of them to produce the foot-candles desired. This suggested a considerable expenditure in maintenance costs. Such indications caused more and more interest in the mercury-vapor sources.

The high efficiency of mercury-vapor lamps merited particular attention. The then recently developed and newly announced 3,000-watt mercury lamp producing 120,000 lumens came in for much careful study. The high lumen output from a single light source was noteworthy from the standpoint of design because of the possibility of reducing the number of light sources required to provide the level of illumination desired. This naturally meant fewer light sources to be maintained.

Additionally, reported experience with smaller sizes of mercury-vapor lamps in other installations suggested the probability that with long hours of burning the useful life of the three-kilowatt lamp would be considerably more than its published life of 2,000 hours. This would add to its value from a maintenance angle. It was felt therefore that the possibilities of using this source should be investigated more carefully. Either alone or in combination with filament lamps, this new illuminant seemed to hold much promise for application design.

The apparent potentialities of the three-kilowatt mercury lamp were not all favorable. The intrinsic brightness of a source of such lumen output meant that a very serious glare problem might be presented. There was also the possibility of very uneven distribution and sharp shadows if a direct-lighting system using this lamp were to be installed. Lamp failures with

Figure 1. Artist's preliminary sketch of Budd Field

Essential substance of a paper presented at the 37th annual meeting of the Illuminating Engineering Society, Chicago, Ill., September 14–16, 1944, and of an address before the AIEE New York Section illumination group, Newark, N. J., October 10, 1944.

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a direct-lighting system might cause very low illumination levels in those areas where the outage of a three-kilowatt lamp occurred. These factors, plus the necessity of evaluating property installations using the other considered sources, led to an analysis of suitable lighting systems.

Many layouts were made using the three types of lamps under consideration in almost every manner in which they could be applied. From these studies, five lighting systems finally were selected for further analysis. These five systems were

(*a*). Direct lighting using 1,500-watt incandescent lamps in porcelain-enameled steel high-bay reflectors on approximately 18-by-20-foot centers.

(*b*). Direct lighting using 400-watt mercury-vapor lamps in porcelain-enameled steel high-bay reflectors on approximately 13-by-13-foot centers.

(*c*). Direct lighting using a combination of 1,500-watt incandescent and 400-watt mercury-vapor lamps in twin porcelain-enameled steel high-bay reflectors on approximately 24-by-22-foot centers.

(*d*). Direct lighting using 100-watt daylight fluorescent lamps in two-lamp porcelain-enameled reflectors mounted in continuous strips on approximately 15-foot spacings.

(*e*). An indirect-lighting system using 3,000-watt mercury-vapor lamps.

Indirect lighting for an industrial plant on such a scale would be a novel experiment. While the many advantages had long been recognized, it had generally been conceded that an indirect system would be so far "out of line" on an economic basis that very few industrial applications had ever been made—particularly for such enormous areas with ceiling heights ranging up to almost 60 feet.

However, many features of this particular project substantiated the idea that a satisfactory and acceptable solution could be obtained with an indirect-lighting system. The curvature of the ceiling of the tunnel-like bays indicated the possibility of using these ceilings as natural reflectors. If a light source of sufficient candlepower could be suspended from the zenith of the arch to approximately the mounting height already established by the limitations of the monorail system, the curvature of the ceiling would act as an integrator to produce almost even illumination throughout the working areas. From such a light-center position, the maximum-to-minimum ratio in distribution of light flux to the floor level was computed to be 1.25 to 1.

The 3,000-watt mercury-vapor lamp gave promise of meeting the existing requirements. It was therefore conceived that a continuous catwalk should be suspended from the center of the ceiling of each bay. In the large bays the catwalk would be suspended 17 feet from the zenith of the arch, thus providing the 41-foot clearance above floor level which was required. In the small bays the catwalks would be suspended the maximum of 9½ feet from the zenith of the arch, providing the clearance of 23 feet 6 inches stipulated for this area. Thus, there was suspended from each arched ceiling a continuous catwalk 1,800 feet long or, in the total of eight catwalks some 2.7 miles of lighting system. On either side of these catwalks were to be mounted specially designed reflectors spaced at regular intervals (Figure 2).

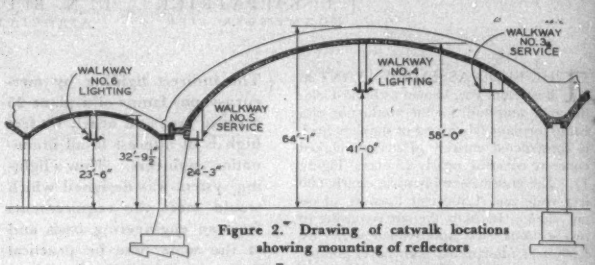

Figure 2. Drawing of catwalk locations showing mounting of reflectors

Fixtures are mounted on both sides of catwalks which are hung from the ceiling. Mounting height is approximately 41 feet in high bays and 23 ½ feet in low bays

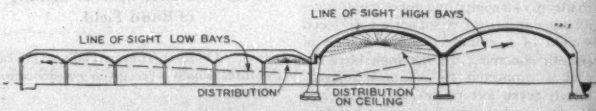

Figure 3. Cross section of building showing relative size of large and small bays and distribution of light on ceiling and shielding angle

Small bays are approximately 50 feet wide and 39 feet to the zenith of the arc; large bays are about 135 feet wide and 58 feet to the top of the arched ceiling

Each reflector was to house a 3,000-watt mercury-vapor lamp, and it was to provide, within the practical limitations of design, an even distribution of flux on the arched ceiling. Additionally, care was to be employed in providing shielding from glare (Figure 3). The concrete ceiling was to be painted a matte white of not less than 80 per cent reflectivity. Furthermore, it was hoped that a white concrete floor could be provided.

A complete estimated cost analysis was made for each of the five systems previously selected. These analyses included the initial investment for luminaires and lamps; the cost of auxiliaries where required, the

Table I. Operation Characteristics of Light Sources

	Fluorescent	Incandescent	Mercury	Combination Incandescent and Mercury
Starting time	2–3 seconds delay Special ballasts—instant	Instant	Instant, but requires 3–5 minutes to reach full output	See components
Restarting after power interruption	2–3 seconds delay Special ballasts—instant	Instant	Requires 3–10 minutes to cool before arc re-establishes	See components
Rated average life (published data)	40 watts—2,500 hours 100 watts—3,000 hours	1,000 hours	400 watts—3,000 hours 3,000 watts—2,000 hours	See components
Removal after failure	Unless "no-blink" starter or instant ballasts are used, should be removed immediately	At convenience	At convenience	See components
Accessories required	Ballast transformer and starter	Self-contained	Ballast transformer	See components
Power factor	Correction to 95–99 per cent	100 per cent—no correction required	Correction to 95–98 per cent	See components
Sensitivity to voltage variation	See graph *A*	See graph *B*	See graph *C*	
List price	40 watts white —$0.95 40 watts daylight— 0.95 100 watts white — 2.15 100 watts daylight— 2.15	500 watts—$1.20 750 watts— 3.45 1,000 watts— 3.70 1,500 watts— 5.55	400 watts—$9.50 3,000 watts—40.00	See components

cost of installation; the cost of walkways where recommended; the cost of service trucks where suggested; the cost of painting where essential to the lighting system. Then, this initial investment for each system was amortized on a basis of eight years, five years, and three years. Additionally, the service costs were analyzed, establishing the kilowatt demand; the kilowatt-hours per year on 8,000, 5,000, and 3,000 hours burning; the annual energy cost on the same basis; the number and cost of lamp renewals; the man-hours for relamping and servicing of each unit; the actual maintenance cost of labor, and, additionally, the cost of repainting the interior of the plant where recommended as a specific requirement for lighting purposes. Thus, for each system, there was an estimate of the annual servicing cost plus the annual capital charges. The result of these studies pointed to the probability that the totally indirect 3,000-watt mercury system could be justified on an economic basis.

In order to prove the practicability of such a system, a scale model was built. About six feet wide, three feet high, and approximately 30 feet long, the model represented one-third the full length of a high bay in 1/20th scale. To simulate the recommended lighting system, high-voltage fluorescent tubing with white cardboard reflectors was installed. The lumen output of the tubing was calculated to be within practical limits of the 1/20th scale of the model. It was anticipated that the results produced would give some approximation of the results which could be expected in the final installation. One change was made in the model; namely, solid walls were substituted for the open areas with supporting columns on 40-foot centers. However, it was estimated that the reflectivity obtained from these walls would not be in excess of the total flux contributed by the spill light from other bays when the entire system was in operation.

The entire interior of the model was painted with a white matte finish having an 88 per cent reflection factor. This, of course, was an ideal condition but was impractical because the floor would have to be painted to attain such efficiency. Illumination readings under these conditions averaged about 80 foot-candles at a normal working plane with a variation of less than 1.2 to 1 over the entire area. The next step was to paint the floor of the model with a matte paint of 65 per cent reflection factor. This reflectivity was equivalent to results attainable from a white cement floor. Illumination readings taken under these conditions produced an average of about 65 foot-candles with the same maintenance of distribution ratio. The third step was to paint the floor of the model a matte finish of 28 per cent reflection factor. This represented a reflectivity equivalent to results attainable from standard gray cement floors. Illumination readings under these conditions produced an average of about 45 foot-candles. Excellent uniformity in both horizontal and vertical foot-candles was found at various elevations above the floor level.

When these data were analyzed and the clean and cheerful appearance of the lighting system in the model was observed, it was resolved that a system of this type should be installed. Only one modification was made. Since considerable female help would be employed in this plant, and it was realized that the employees might object to the effect on their personal appearance of the blue-green predominance of a straight mercury-vapor installation, it was decided that an incandescent component should be added.

Electric service for the entire plant is furnished by the Philadelphia Electric Company at 66,000 volts and is stepped down at the main substation to 13,200 volts. Power is transmitted at this voltage through underground ducts to eight indoor substations in the assembly building.

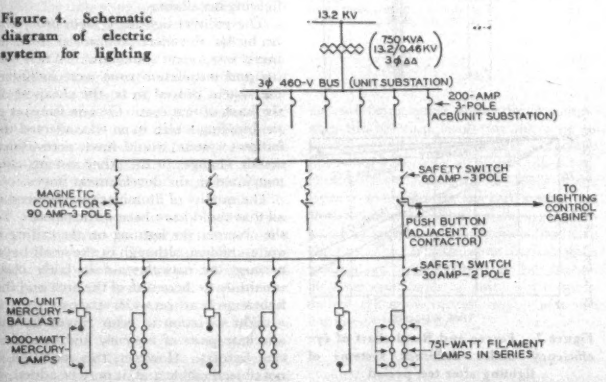

Figure 4. Schematic diagram of electric system for lighting

Located at each of the eight substations is a 750-kva transformer for lighting service. Each transformer steps down the potential from 13.2 kv to 460 volts whence it is distributed by a three-phase bus through six 200-ampere three-pole air circuit breakers incorporated in a unit substation. From each air circuit breaker service is carried to a section of the catwalk where it is split into several lighting circuits. Each lighting circuit is protected by a 60-ampere three-pole safety switch and is remotely energized by a pilot circuit operating a 90-ampere three-pole magnetic contactor. Each lighting circuit feeds 12 lighting units which are electrically connected in pairs. A pair consists of two units of the same type, that is, either incandescent or mercury, located physically opposite each other on either side of the catwalk. The lead wires to a pair carry through a fused safety switch and thence directly to the units in the case of incandescent fixtures or through a two-lamp ballast and then to the reflectors in the case of the mercury fixtures. Switching control of pairs of reflectors or groups of reflectors on the catwalk permits isolation of units for servicing (Figure 4). Such safety measures made possible the use of 460-volt three-phase three-wire lighting-distribution circuits. Normal control of the lighting system is performed through the operation of push buttons in the lighting panels conveniently located throughout the plant. This operation energizes pilot circuits which activate the magnetic contactors which in turn control the groups of fixtures. This group control through the magnetic contactors is so arranged that selective sections of a continuous bay may be lighted or cut out if production schedules indicate the desirability of such procedure. The distribution wires are carried in a square duct laid on the floor of one side of the catwalk and, then directly to the fused safety switches controlling the pairs of mercury and incandescent units. A separate substation is provided to supply emergency lighting in case of failure of the normal incoming power lines.

Since this was a wartime project, in

Figure 5. View of catwalk from floor

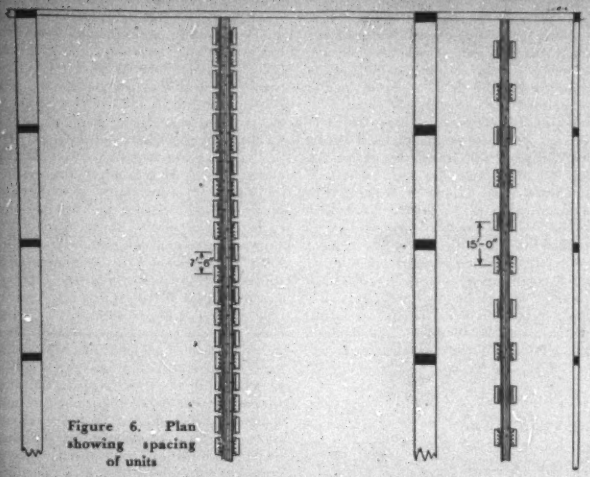

Figure 6. Plan showing spacing of units

addition to seeking the best possible illumination, it was necessary to give serious consideration to the conservation of critical materials. The indirect-lighting system as conceived was a step in this direction. The higher voltage and concentration of the lighting circuits produced drastic savings in copper. The relatively small number of fixtures needed to produce the desired quality of lighting also effected marked economies in the amount of critical materials used. A glazed-finish porcelain-enameled steel was selected for the reflector, a second choice to specular Alzak aluminum which was unavailable at that time because of war restrictions. However, the semispecularity of the glazed-porcelain enamel gave promise of producing satisfactory results.

The reflectors for both the mercury and incandescent lamps are very similar in appearance, particularly when viewed from the ground (Figure 5). Each unit is about 72 inches long, about 18 inches high, and 22 inches wide. Each mercury reflector holds one 3,000-watt lamp. Each incandescent reflector is equipped with four sockets so wired that 115-volt lamps burning in series operate directly on the 460-volt distribution system. The lamps are of the arc-resisting type which are so designed that on lamp failure the arc is quenched within the bulb. The sockets are mounted on adjustable supports, so that various lamp sizes can be properly positioned in the reflectors. In the high bays 751-watt lamps are used and in the low bays 501-watt lamps.

The reflectors are mounted on either side of the catwalks by means of a pair of bracket arms which are attached to the main channels of the catwalk structure. The reflectors are adjustable, and the brackets are equipped with stops so that

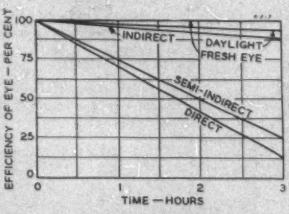

Figure 7. Ferree and Rand chart of eye efficiency under different systems of lighting after test period

the units can be tilted back to a servicing position and returned to their original setting. A clamp-type locking device also is incorporated. Along a catwalk the pairs are alternately filament and mercury. In the low bays the spacing between units is 15 feet, and in the high bays the spacing is $7^1/_2$ feet (Figure 6).

This lighting system is carried throughout the entire building with two exceptions. The assembly processes required a "dope room" which had to be isolated completely from the remainder of the plant and which necessitated the use of vapor-proof and explosion-proof lighting equipment. This dope room, 200 feet long and 100 feet wide, is a completely walled-in enclosure which breaks the continuity of the lighting system in two of the small bays. The second exception is in the low bay at the south side of the building. This bay is devoted to receiving and shipping, and approximately half of the floor area is taken up with sidings for freight cars. In this bay the catwalk was installed, but reflectors are mounted only on the north side of the catwalk. These two variations are the only exceptions in the continuity of the lighting system as described.

During the period of installation, Government restrictions on materials became even more severe. As a result, the plan for a white concrete floor was abandoned. Also, paint manufacturers were deprived of certain ingredients needed for the ceiling that had been decided on; consequently, the finished ceiling, instead of having an anticipated minimum reflectivity of around 80 per cent, actually produced about 65 per cent.

At the time the plant was taken over by the Budd Company, an engineer was given complete responsibility for the lighting system. This engineer with his crew has been servicing the installation for nearly one year of operation. His records and reports provide the data which gave a clear-cut picture of the performance of this lighting installation.

The indirect lighting system proved to be by far the most economical from an initial investment standpoint. When wiring and installation costs were included, the system proved to be the cheapest on the basis of first cost. Certain features of the building which in no wise affected the indirect system would have necessitated drastic changes in the other systems contemplated in the development stages.

The quality of illumination produced is all that could have been anticipated. To the observer the lighting on the ceiling is quite uniform, although in the small bays, because the catwalks are in fairly close proximity to the zenith of the arch and the light sources are on wider spacings, there is a slight variation in color caused by the alternate pairs of mercury and incandescent fixtures. However, this condition is not objectionable and, it may be added, is not particularly noticeable except to the critical observer. The ceiling brightness does not exceed 250 foot-lamberts. The distribution of light is excellent, producing a soft well-diffused illumination with a minimum of shadows.

The general appearance of the lighting system is functional and neat and produces an interior which is bright and cheerful.

When the installation first was put into service, illumination values were in the range of 45 to 50 foot-candles. The findings of Ferree and Rand (Figure 7) in their researches on eye efficiency under various systems of lighting indicated that indirect lighting could be given a much higher evaluation than other systems. Experiments in the plant showed that less foot-candles of indirect lighting would produce equal or better seeing conditions than a direct-lighting system of more foot-candles. This was proved in the few locations where local lighting was used. In spite of the fact that well-diffused low-brightness units were developed for the supplementary lighting, the high specularity of stainless-steel surfaces made long-period seeing conditions almost intolerable. Therefore it was believed that if 35 to 50 foot-candles of direct

lighting were considered adequate for war production, then a somewhat lower level of totally indirect lighting would provide at least equivalent and probably better seeing conditions. The first step was to introduce 120-volt incandescent lamps in place of the 115-volt lamps which were installed originally. This change obtained about 50 per cent longer average life for the filament sources while it also meant about 14 per cent reduction in the lumen output of these sources. It should be noted, however, that the incandescent component represents only one third of the total. Thus the loss in total lumens from this procedure was only about four per cent.

The three-kilowatt mercury-vapor lamp was such a recent development at the time the assembly plant was put into operation that few data on performance in the field were available. It was anticipated that under the operating conditions on this job the three-kilowatt lamp would have a life considerably in excess of its published rating of 2,000 hours, and that its efficiency would be fairly satisfactory throughout most of the operating period. The only way to determine the useful life in active service was to keep the three-kilowatt lamps in operation until failure occurred. Accurate records of ten months of service show that these sources have been operating on an average of 15 to 18 hours daily or a total of approximately 5,000 hours with only seven per cent replacements for the entire period. The available data also show that these lamps are producing about 75 per cent of their initial rated lumens output after the ten months of operation. The losses incurred in the execution of these procedures together with an estimated average depreciation of ten per cent in lumen output for the filament lamps result in a drop of approximately 23 per cent in resultant illumination values. On the basis of initial utilization, with no depreciation, this would mean an expectancy of about 36 foot-candles.

Of course, there has been a depreciation from the initial efficiency of the over-all system, which normally might be expected to reduce as much as 50 or 60 per cent. However, the assembly operations performed in Budd Field are particularly clean, and excellent housekeeping is required, especially in connection with the lighting system. The forethought in providing lighting catwalks makes maintenance easy, safe, and economical. Thus today the average illumination throughout the plant is approximately 30 foot-candles. This means a depreciation in utilization of about 20 per cent which for an indirect-lighting system, and particularly an indirect-lighting system in an industrial plant, is noteworthy.

It must be remembered that this lighting system is a new and somewhat radical design; that it was installed under the limitations of wartime conservation; that it is in the first year of its operation; and that, therefore, many experiments have been and are being made to determine acceptable illumination levels for the type of work, together with the most economic operating basis with all factors taken into consideration. Also, the efficiency of the light sources and the over-all system are both at low ebb. When relamping and repainting are put on a schedule where they do not occur at the same period, then maintained utilization will be higher. Postwar application of paint will result in better reflection factors, which also will improve utilization.

Table II. Annual Cost of Operation, Entire Plant—Three-Year Amortization

System	Large and Small Bays, 1,500-Watt Incandescent Lamp in High-Bay Reflector—Direct Lighting	Large and Small Bays, 400-Watt Mercury Lamp in High-Bay Reflector—Direct Lighting	Large and Small Bays, 1,500-Watt Incandescent and 400-Watt Mercury Lamps in Twin High-Bay Reflectors—Direct Lighting	Large and Small Bays, 100-Watt Fluorescent Lamp—Direct Lighting	Large and Small Bays, 3,000-Watt Mercury Lamp—Indirect Lighting
8,000 hours burning					
Equipment	$ 29,344.65	$ 81,296.24	$ 32,411.89	$ 204,161.60	$ 95,100.00
Energy	327,120.00	191,382.00	279,256.00	228,944.00	390,720.00
Lamp renewals	74,365.28	105,476.00	83,465.06	175,868.16	169,160.00
Maintenance	163,550.00	331,920.00	216,480.00	780,460.00	45,998.00
Total	$594,379.93	$710,074.24	$611,612.95	$1,389,433.76	$700,978.00
5,000 hours burning					
Equipment	$ 29,344.65	$ 81,296.42	$ 32,411.89	$ 204,161.60	$ 95,100.00
Energy	204,450.00	120,220.00	174,535.00	143,090.00	244,200.00
Lamp renewals	46,478.30	65,923.00	52,165.66	109,917.60	108,225.00
Maintenance	163,550.00	331,920.00	216,480.00	780,460.00	45,998.00
Total	$443,822.95	$599,359.42	$475,592.55	$1,337,629.20	$493,523.00
3,000 hours burning					
Equipment	$ 29,344.65	$ 81,296.24	$ 32,411.89	$ 204,161.60	$ 95,100.00
Energy	122,670.00	72,132.00	104,721.00	85,854.00	146,516.00
Lamp renewals	27,886.98	39,553.80	31,317.73	65,950.56	64,935.00
Maintenance	163,550.00	331,920.00	216,480.00	780,460.00	45,998.00
Total	$343,451.63	$524,902.04	$384,930.62	$1,136,426.16	$352,549.00

Sufficient information has been obtained from the Budd Field installation to warrant such consideration of future trends in industrial lighting. Here is a large-scale indirect-lighting installation where energy consumption is high, averaging approximately six watts per square foot. Lamp replacements for the incandescent component have increased maintenance costs. In spite of these factors, the annual cost of operation is considerably lower than the original figures, and the savings in production efficiency are enormous.

Figure 8. View of the Budd plant from the floor

Recent Electron-Tube Developments

S. B. INGRAM
MEMBER AIEE

Electron tubes first were used in telephone systems chiefly for speech transmission; they now are being used extensively for many other purposes. A few specially developed amplifier tubes and some typical tubes used in the nontransmission part of the telephone plant are described in this article.

THE MAIN APPLICATIONS of electronics, at least until recent years, have been in the field of communication. Modern systems of radio and long-distance-telephone communication would be impossible without the electron tube. No alternative means generally have been available to perform the functions which the electron tube performs in the transmission of speech in communication systems and these functions were not performed at all until the electron tube came along. Of recent years electronics is receiving more extensive use in industry. The functions which the electronic devices are performing there are generally not new functions. They have been performed in the past by other means and the reason that the electron tube is being applied is that the electron tube can do an old function in a new and better way. A parallel development has been taking place in the telephone industry. For a long time although electronics was applied widely to telephony practically all the extensive uses had to do with the actual transmission of speech. Electron tubes now are beginning to play a much more important part in the operation of the nontransmission part of the telephone plant and are being used widely to perform the functions formerly performed by switches, relays, signaling devices, and rotating machines. This article attempts to survey, in a necessarily sketchy fashion, some of the recent applications of electron tubes to both the transmission and nontransmission parts of the telephone plant and to describe some of the tubes which have been developed for these uses. No attempt has been made at completeness and only the broad outlines of recent electronic developments in the telephone system are drawn.

TELEPHONE-REPEATER TUBES

In the transmission field recent long-distance telephone systems are largely of the carrier type where one pair of conductors carries more than one communication channel. The carrier systems are of three kinds, carrier on open wire, on small-gauge cable, and on coaxial cable. In many cases the first and second systems have been used to increase the capacity of wire facilities which already exist. By the addition of repeater stations at suitable intervals and of appropriate terminal equipment as many as 16 individual conversations can be transmitted over a single open-wire pair and as many as 12 over two pairs in conventional small-gauge telephone cables. In the coaxial system 480 telephone circuits may operate simultaneously over two coaxial pairs of conductors. Carrier systems of all types use as repeaters broad-band amplifiers of the negative-feedback type and have called for the development of special amplifier tubes to give the performance best adapted to the requirements of the over-all system.

In the design of tubes for broad-band amplifiers high transconductance and low input and output capacitance are desired. The maximum amplifier band width obtainable with a given tube is determined by a so-called "figure of merit" which may be defined as the ratio of the transconductance to the sum of the input and output capacitances. In practice, the figure of merit can be increased to its highest obtainable value only by using the smallest grid–cathode spacing it is possible to realize mechanically. Other desirable characteristics in tubes for telephone-repeater use are low filament-power consumption and long life. Long tube life is a factor of exceptional importance in all long-distance telephone systems. In the carrier systems particularly the maintenance of high quality of service requires that tube failures be reduced to a minimum because each tube is associated with a large number of circuits and each long-distance connection passes through a large number of tubes.

Figure 1 shows the 384*A* or 386*A* coaxial-cable amplifier tubes. These tubes are identical in appearance, differing only in internal structure. They are pentodes with small indirectly heated cathodes of one watt power consumption. A high transconductance has been obtained by the use of the indirectly heated cathode and a very small grid–cathode spacing, 0.004 inch. The figures of merit as defined hereinbefore are about 500 for the 384*A* and 725 for the 386*A*. When used as power output tubes in the coaxial system at 120 volts on the plate and working into 10,000 ohms impedance the 384*A* delivers 100 milliwatts and the 386*A* 250 milliwatts with harmonics 20 decibels or more down. With these tubes the line amplifiers have a useful band width of three megacycles.

Figure 2 shows the 373*A* and 374*A* tubes, the voltage- and power-amplifier tubes, respectively, for the most recent carrier-on-cable system. These tubes are pentodes with filamentary cathodes of $^1/_2$ and $1^1/_2$ watts power consumption. The transconductances are 1,300 and 3,000, respectively, and the power output of the 374*A* is 1.3 watts with the second and third harmonics about 20 decibels down.

TUBES FOR RADIOTELEPHONE

The radio part of the telephone-communication system is expanding rapidly. Transoceanic and ship-to-shore radio play an important part in linking the entire world by one continuous interconnected telephone network. The growth of wire carrier systems, as well as the increasing traffic on existing radiotelephone channels, has given an impetus to the study of multiplex radiotelephone systems capable of transmitting simultaneously a number of conversations associated with one carrier frequency. An interesting example is the 12-channel 160-megacycle system operating between Cape Charles and Norfolk, Va. Here a 26-mile radio link across the mouth of Chesapeake Bay carries traffic which otherwise would have to be routed around the bay by way of Baltimore and Washington, a distance of 450 miles. The system is capable of accepting and delivering the 12 channels of the standard type *K* carrier-on-cable system which lies in the 12- to 60-kilocycle band.

Multiplex radio systems place much more severe requirements on the fidelity of the radio transmitter and receiver than

Figure 1. Coaxial-cable-amplifier tubes 384A or 386A, which differ only in internal element structure

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are commonly met with in single-channel transmission. This fidelity is necessary to avoid intermodulation between channels. To obtain this high degree of fidelity, while still maintaining efficiency by using signal amplitudes comparable with the rated output of the tubes in the final stage, negative feedback has been employed. The circuit problems of this system are complex, and their solution would have proved much more difficult without the introduction of several new tubes specially designed for this system. The novel features of these tubes will be useful in other applications.

The output stage of the Cape Charles system consists of a pair of 50-watt triodes operated push-pull in a bridge neutralized circuit, plate modulated by a 350-watt pentode. The triodes, known as 364*A* tubes, are a redesign of the older 356*A* tube. Both tubes are shown for comparison in Figure 3. The improvements, all contributing to improved performance at the high frequencies, are decrease of the transit time by use of smaller grid–filament spacing, shortening of all electrode leads to reduce their inductance, and the bringing out of duplicate plate and grid leads through the glass envelope. The first and last of these features, particularly, are of importance in the design of the multiplex circuit. This is because phase modulation of the output results in distortion and therefore intermodulation between channels, and phase modulation can arise either from variation of transit time with modulating voltage or from the presence of any impedance common to the input and neutralizing circuits.

The 350-watt pentode is used in the Cape Charles system to plate modulate the 364*A* tubes because it is capable of delivering 65 watts of audio-frequency power at 1,250 volts to the 7,000 ohm impedance presented by the two triodes, with distortion less than that contributed by the modulated stage itself. No other available tube is capable of this performance. While the tube is used here in class *A* operation at carrier frequencies up to only 60 kilocycles, its possibilities are perhaps most interesting in the ultrahigh-frequency

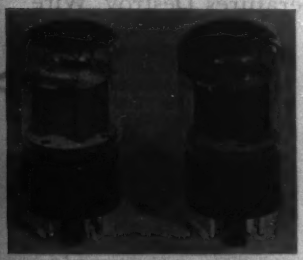

Figure 2. Amplifier tubes for carrier on cable system

(A)—373A (B)—374A

field. It is designed with short electrode leads of low inductance and is capable of operating at full ratings up to 85 megacycles. Thorough shielding reduces the grid–plate capacitance to 0.06 micromicrofarad. This shielding includes a plane shield at suppressor-grid potential, running laterally across the tube to the glass walls, and designed for extension outside the envelope by the circuit shielding. The transconductance of the tube is 12,000 micromhos, and the input and output capacitances are 29 and 21 micromicrofarads, respectively. The tube has a 100-watt thoriated-tungsten filament. It is known as the 363*A* and s illustrated in Figure 4.

THYRATRONS FOR BATTERY CHARGING

Every telephone central office has a reserve power supply to assure continuity of service when the primary power supply is interrupted. This reserve is generally a storage battery. The charging of the largest of these batteries in power plants where the drain may run to hundreds of amperes is done most economically by motor generators. Formerly the chargers used in the smaller power plants were of the same kind used in garages, that is, manually controlled rectifiers of the so-called Tungar type. During the last ten years, these have been rapidly replaced by regulated rectifiers using thyratron tubes.[1] A number of advantages in operation and maintenance are gained by the use of this modern equipment. The regulated rectifiers maintain the battery terminal voltage at a constant value, independent of variations in load and line voltage. Fluctuations in current drain automatically are taken care of by variations in the output of the rectifier so that, under normal circumstances, the battery is maintained in a stand-by floating condition. This greatly increases battery life and has the added system advantage that the direct voltage is maintained approximately constant instead of fluctuating over wide limits during the cycle of charge and discharge.

Three-element thyratron tubes have been used in these regulated rectifiers. An innovation has been to fill the tubes with a mixture of mercury vapor and argon at a pressure of approximately 100 microns.[2] Thyratrons have commonly been made with either mercury-vapor or rare-gas fillings. Mercury-vapor tubes are desirable because of their long operating life and low tube drop which permits high circuit efficiency. They have one undesirable feature, the dependence of their grid characteristic on temperature and their inability to operate satisfactorily at low ambient temperatures. Rare-gas-filled tubes, while lacking the latter limitations, are not yet available with life expectancies of greater than a few thousand hours. The gas-mixture tubes combine the advantages of both types, possessing temperature stability and at the same time maintaining a low drop throughout a long

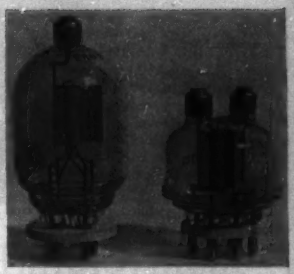

Figure 3. Fifty-watt triodes

(A)—356A (B)—364A—output tube for Cape Charles transmitter

Figure 4. Type 363A 350-watt ultrahigh-frequency pentode used as modulator in Cape Charles transmitter

service life, 10,000 to 20,000 hours in typical telephone service. The earlier tubes of this type were limited in their inverse voltage rating to about 500 volts because of the presence of the 100-micron pressure of argon. Increase of this rating by the reduction of gas pressure was found to be impossible without running into danger of gas cleanup, but a modification in the tube geometry in which the grid and anode structure are closely inserted into the confined space of the dome of the glass envelope gave substantial improvement. This so restricted the length of electron paths in the grid–anode region where the high fields occur that such tubes are capable of withstanding considerably higher voltages than the earlier unshielded tubes. The most recently developed tubes of this type are rated in inverse voltage as high as 1,250 volts and can be used in single-phase regulated rectifiers with d-c outputs

up to 350 volts. Figure 5 shows one of the older designs, a Western Electric 323*A* tube, compared with the newer 393*A*, which is the same in its characteristics except for the higher inverse-voltage rating. These tubes are rated at 1.25 amperes average anode current. The 394*A*, a smaller tube with half the filament power and anode current rating, is also shown.

COLD-CATHODE TUBES

Cold-cathode gas-filled tubes have found extensive application in the telephone plant.[3] Since they require no filament power, they are admirably adapted for the intermittent type of service frequently encountered in telephone equipment. Fundamentally, small thyratrons could be used in most places where cold-cathode tubes have been applied, but the filament-power consumption would be prohibitively costly. In some cases, for example in subscriber-station equipment, local filament battery would have to be installed making their use on any extensive scale quite impractical. Furthermore, all thermionic tubes have a relatively short life expressed in terms of years even when operating in stand-by service with no plate current flowing. Cold-cathode tubes, by contrast, when operated on light duty will supply many years of trouble-free service without replacement. In many places in the telephone plant such tubes are soldered in place because they are not considered to be replaceable items.

The use of cold-cathode tubes for four-party selective ringing in which the tube is used as a rectifier in series with the subscriber's ringer to discriminate between positive and negative polarity of ringing voltage has been described previously[4] and is no longer new. It is important because of its extensive use running to hundreds of thousands of such installations. The tubes used, the Western Electric 313*C*, 333*A*, and 372*A*, which differ only in basing arrangement have also been described before. Figure 6 shows the structure of the 313*C* tube and compares it with that of the 359*A*, a more recent development. This latter tube is one with about the same characteristics as the 313*C* but much smaller in size and rated at about one half of the current. The economy in size is obtained by the compact internal arrangement of the elements. The cathode is a coated nickel cylinder, crimped at the top and supported from the glass wall by molybdenum springs. The control anode is a small nickel wire spaced but a small distance from the cap which closes the lower end of the cylinder. The anode is a wire extending through a mica disk which rests directly on the top of the glass press and shields it from deposits of getter material, cathode coating, or other substances which might cause electrical leak between the elements. Breakdown between the leads is prevented by glass sleeves which are not sealed to the press, but extend through the mica shield.

Figure 5. Thyratrons used in regulated rectifiers for battery charging in telephone central offices

(*A*)—323*A* (*B*)—393*A* (*C*)—394*A*

Figure 6. Cold-cathode tubes used in the telephone plant

(*A*)—313*C* (*B*)—359*A*

Extreme mechanical ruggedness is a feature of the design.

The principal application of this tube to date is in a small secretarial board at which an attendant can pick up any one of 10 or 20 subscriber's lines.[5] A tube is associated with each line and is operated by a ringing voltage coming over the line from the central office. An audible ringer is placed in the lead common to the anodes of all the tubes to attract the attention of the attendant if absent from her desk when a call is received. The correct called line can then be identified by noting which tube lights. The tube thus serves the dual purpose of relay and visual signal.

Another extensive application of cold-cathode tubes, interesting because of the nature of the function which the tube performs and important because of the number of tubes involved, is a registration system for use in large metropolitan areas. Central-office battery is commonly 48 volts. This voltage is insufficient to break down a cold-cathode tube so the tube may be placed between the line and ground without introducing transmission loss or noise into the talking circuit. The system provides that when the operation of the registration feature is required higher-voltage pulses simplexed over the loop from a tandem office to the central office break down the tube and operate a relay in its anode circuit. It thus operates as a relay which has infinite impedance to the voltages ordinarily encountered during conversation. In the largest application of the arrangement which is in New York, N. Y., approximately 50,000 tubes are installed. The tube used, the 346*B*, is similar to the 313 type, but has a longer cathode–anode spacing and a higher argon concentration to give it the higher main-gap breakdown voltage required by the application.

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High Soldering Temperatures Destroy Wire

That temperatures and operation times commonly used in soldering copper wire reduce wire diameter, decrease its life, and even totally destroy it, was discovered by the engineers of the Fairchild Camera and Instrument Corporation during an investigation of a single-step hot-tin-strip method of stripping and tinning copper wire.

Tests disclosed that with increased working temperatures and tin content of the solder went greater likelihood of wire destruction. Reduction in operating time attendant upon higher temperatures was not sufficient to forestall destruction of very fine wires. Unfortunately also, an all-lead solder results in a considerably weaker joint than a tin–lead solder.

Destruction of the copper is believed to be an alloying away of the copper largely by the tin in the solder. The wire embrittlement occurring at high temperatures is caused by a subsurface coarsening of the copper crystals and the formation of a hard foreign substance between the solder and the copper zones.

The data indicate that on wire sizes finer than approximately number 30 or 32 wire, temperatures for tinning and making joints should be kept under 600 degrees Fahrenheit and that a 40 per cent tin, 60 per cent lead, solder should be used.

IX—Research—Creator of Employment

A. W. HULL

In this article a physicist offers his views on how research can promote progress and ameliorate unemployment rather than an engineering analysis of what present methods and machines lack. The developments recommended are not mere revisions of existing techniques but signposts to untried paths.

SEVERAL new factors call for increased industrial research after the war. One is a growing belief that research pays. Another is the force of public opinion, which is becoming research conscious, so that customers and stockholders will give preference to those companies which have active research programs. A third new factor is the threat of government action. Government will step in to satisfy the public demand for research, if industry fails to do so. Certain types of fundamental research are proper government activities, but other types, especially the later development stages of research, cannot be separated from responsibility for production. Many believe that government should not enter this field.

The most important reason for increased research, however, is its effect on employment. It generally is agreed that our number-one enemy after the war will be unemployment—not the temporary dislocation of reconversion but the malignant disease. The battle against it will be long and difficult, and we shall need new weapons. One of the most effective of these is research.

In the past, research has helped combat unemployment by developing new products and more efficient methods, which stimulated business. Its most important service, however, is yet to come, and the rapidly growing appreciation of research gives promise that it will come. That service is to keep alive the spirit of progress and adventure which made our country prosperous in the past and can continue to make it more and more prosperous in the future. Will the fountains of prosperity become exhausted? Every scientist would answer "No; we have scarcely scratched the surface of scientific exploration."

PROGRESS VERSUS INERTIA

Unemployment goes with a static economy, which human beings, particularly Americans, detest. We are happy only when we are progressing. Inertia is intolerable. In this we are like children building with blocks. The child's happiness changes to gloom when the last block has been placed on his castle. He is unhappy because, like Alexander the Great, he can see no more worlds to conquer. It was not the castle which he wanted, but the pleasure of building it. So with the American people, it is the process of getting rich that gives them pleasure, not the wealth. If evidence of this truth be needed, it may be found in the lack of correlation between wealth and happiness. One does not observe that the rich people are the happiest ones, the middle class less happy, and the poor people unhappy. But one does observe that those who are progressing are, as a rule, happy, and those who cannot progress are unhappy. The workman is not satisfied to have his wages high. He wishes to see them increase. The farmer must see his net income grow each year. Business and industry must be expanding to be healthy. Can this expansion continue forever without reaching saturation? Science says yes. Research can provide new products and new methods of production that will keep our scale of living increasing and our economy expanding without limit.

But something more than the *fact* of progress is needed to combat depression and unemployment. There must be a *spirit* of progress, an atmosphere of unlimited horizons and unbounded opportunities, an atmosphere in which fear and defeatism with their offspring of unemployment and want in the midst of plenty, cannot thrive. I believe that scientific research, if sufficiently active, is capable of producing and maintaining this atmosphere.

MORE RESEARCH IS NEEDED

The attainment of this atmosphere of progress and adventure requires a tremendous expansion of research and means a greater expenditure for research in the future than in the past. Can our economy stand such an expenditure? In 1937 the total expenditure for research in the United States[1] was 0.29 per cent of the total national income and 0.64 per cent of the value of the products affected by the research. For the electrical industry the average expenditure was 1.67 per cent of such value, which in this case is the same as gross income. These are large expenditures, but they are small compared to the cost of unemployment. For example, as a result of unemployment the average national income for the ten-year period, 1930–1939, fell short of its 1929 full-employment level by 30 per cent.[2] This loss from unemployment is more than 100 times the total amount spent for research during the same period.

The difference between 0.29 per cent and 30 per cent indicates that the country could afford to spend a much larger fraction of its national income for research, if such expenditure would eliminate unemployment loss or considerably reduce it. Even the 1.67 per cent spent by the electrical industry is small compared to 30 per cent. If research is a good method of combating unemployment, the electrical industry certainly would be justified in doubling its research effort. The limit which such expenditure might reach profitably may be much higher but does not have to be determined at this time, for the rate of research expansion is necessarily slow, being limited by the rate at which qualified research men can be trained.

INDUSTRY CANNOT AFFORD NOT TO DO MORE RESEARCH

Who will pay for this research? Can industry afford to pay for it? The answer

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is that industry cannot afford not to. A list of the profitable lines in the electrical industry shows that a large fraction of them were not in existence 25 years ago: Electric refrigerators; the whole electronic industry, including radio, electronic industrial control, and presently television; mercury turbines; fluorescent lamps; Pyranol capacitors; Spiracore transformers; Alnico magnets, oil-immersed X-ray tubes, Amplidynes, superchargers—the list might be prolonged. If we have courts which are just enough to allow a reasonable equity in products such as those mentioned to the companies which develop them by their research, then the latter companies will be the ones which will stay in business, and those companies which spend nothing for research will lose out.

PROBLEMS AWAITING RESEARCH

Some of the problems which await research can be enumerated, though they are not necessarily the most important ones. In the past the most valuable results of research have been unexpected developments that could not be foreseen. Such discoveries, however, generally are made while working on other problems of the day. So immediate objectives can serve as starting points for fundamental research, in addition to solving practical projects. The following suggestions are the views of a physicist regarding what can be done and not an engineering analysis of what is needed. These things are not needed from the operational standpoint; our present systems work well. They are needed for progress, in order to make the present systems obsolete.

Generation of Electric Power. It was believed 20 years ago that the large steam turbines, developed during the first World War and perfected in the five years following, represented a close approach to the ultimate in generating efficiency. Since that time the efficiency of steam turbogenerators, in kilowatt-hours per pound of coal, has nearly doubled, thanks largely to metallurgical research; and the mercury turbine has added another 14 per cent. Is this then the ultimate? No, it now appears possible that a still further advance can be made by the gas turbine, a promising project for research. The gas turbine will need steel which is still stronger at high temperature. Thus research in metallurgy is a necessary part of electrical engineering.

The use of higher frequency for the generated power can reduce the weight of generators, transformers, and motors. This demands further research on low-loss transformer steel, another metallurgical problem. Experimentation on the use of higher frequency in power systems can be facilitated by the use of d-c transmission links between the generating stations and the power systems which they feed. This calls for electronic research on the conversion of alternating current to direct current and vice versa.

More important than improvement in turbogenerators is research on water-power generation of electricity, in view of our limited coal supply. I am not one of those who worries about what future generations will do—they will wish to have the pleasure of solving their own problems. But nobody likes waste, and the use of limited coal in place of unlimited water is waste, providing both cost the same. Research on water-power generation and transmission of electric energy can enable it to compete with generation from coal. The electrical industry should cease looking upon water-power generators as stepchildren, and give them the benefit of greatly increased research effort.

Underground Power Transmission. The desirability of putting electric power lines under the ground is unquestioned. Since there is no immediate need for it, however, research in this direction can be justified only on the basis of safety, or esthetic value, or of eventual cost reduction. Underground transmission looks like a good bet from the cost standpoint. Two recent economic changes are in its favor, namely, the increased cost of labor, which demands troubleproof installations, and the decreased cost of money, which justifies larger investment in permanent equipment. Many research problems are involved. One of the most important is a cable-covering material which is resistant to abrasion and immune to electrolysis and bacterial decay. Plastic materials answering these specifications are almost in sight. That is a problem in chemical research. Another problem is the study of incipient corona in cables, which eventually breaks down the insulation. Or does it, if the insulation and gases are of the right composition? What is the mechanism of breakdown of solid insulation?

Ten years ago it was estimated that 500 miles was the maximum practical distance for d-c power transmission. Today the decrease in the cost of money would justify twice as great an investment in copper; for example, a cable of the same size but twice as long. Its resistance would be twice as great, hence only 70 per cent as much power could be sent over it at the same power loss. But, if the cable were improved by research so that it would stand 40 per cent more voltage, then 100 per cent power could be sent over it for the same power loss. This would make the 1,000-mile cable of tomorrow as efficient and as economical in cost as the 500-mile cable of ten years ago.

One of the most interesting features of power-transmission research is its electronic component. This will be of increasing importance. Whether the underground transmission utilizes alternating current which is stabilized electronically, or uses direct current, rectified at the generating end and inverted back to alternating current at the receiving end, electronic tubes and electronic research will be needed. Thyratron tubes will be required which can control at least 200 amperes at 20,000 volts, and have a life expectancy of 10 to 20 years. Such tubes have been produced in the laboratory, and their commercial development awaits only applications.

Research on such underground electric-power transmission can be carried out on a small scale without the necessity of a decision on whether an a-c system or d-c system shall be used. This is possible because the transmission link, especially if it is a d-c link, can be inserted in either system without disturbing it. Even if the research involves a constant-current d-c link, which gives minimum cost of electronic equipment, there is no effect on the system, the power being transformed from the alternating constant voltage of the power system to direct constant current at one end, and back again at the other end. This makes research at moderate cost possible.

Electric Refrigeration. One frequently hears, "Washington would be a fine place to live, if the summers were not so intolerably hot, especially the nights." Similarly, "My chief memory of English universities is the freezing lecture halls." The conditions underlying these statements are the same. The English consider central heating a luxury; we hold the same opinion about cooling. We view the expenditure of $100 to $200 per year for heat as a necessity, but recoil from the idea of a comparable expenditure in order to be comfortable in summer. Although these attitudes are matters of mass psychology, they are influenced by the availability and cost of equipment. It is a safe guess that home cooling will become common in this country when sufficiently good and cheap coolers are available. Thus there is an excellent field for research in home cooling refrigeration equipment. Foremost is the question of the cost of equipment, which must be reduced by research; but many other problems for research are involved, such as noiseless blowers, humidity control, moisture proof walls, and hermetic double windows. The problem of using refrigeration equipment for heating at an efficiency of 400 per cent or higher is a fascinating one, and a single unit for heating and cooling should be practical for moderate climates, where the heating and cooling loads are of the order of four to one.

Home cooling involves the whole problem of home building, since, like central heating, it must be built in and requires special construction. This home problem is one of the most important fields of postwar research. The electrical industry should have a large part in this research, since it now supplies much of the built-in comfort of the home, and can supply still more with research. For example, dust, a major enemy of every good housekeeper, can and should be kept out by the same means which exclude cold and heat and water vapor.

Refrigeration of food is destined to play

a much larger role in the future. With domestic service scarce or nonexistent and a larger fraction of women in factory and office jobs, factory-prepared food will be in greater demand. It is safe to say that we have scarcely scratched the surface of the problem of preparing and preserving food. Much more research is needed on new methods and new containers, on high-frequency electric cooking, and on vacuum dehydration. Especially there is need for fundamental research on the physical and chemical changes that accompany freezing, heating, and drying.

Electronics. Electronics was old yesterday, with radio approaching saturation. Today it is new, with a large and interesting future before it. New devices and new attitudes have wrought the change.

Television is imminent, but requires much more research before it is entirely acceptable and then still more in the never-ending pursuit of perfection. Better camera tubes, larger pictures, more perfect synchronization, and simpler and cheaper circuits are obvious objectives. An extension of the frequency range, which will be possible with war-developed tubes, will provide sufficient band width for frequency modulation of the video signals, if this be found desirable. Present methods of frequency modulation cannot be used at these high frequencies, and new ones must be found by research. There also will be room enough for color television, which will be a research problem for a long time. It can be produced by mechanical scanning, but surely there is a better way.

Electronic industrial control is especially deserving of research, because it is one of the most effective weapons for fighting unemployment. At first sight it appears just the opposite; a device which enables one man to do the work of two would throw half of the men working out of work. this would be true, if the new device were introduced suddenly and if the amount of work were limited. But it cannot be introduced suddenly, because such devices require time and experience and research for their introduction; and the amount of work in the world is infinite, being limited only by human wants, which are insatiable. It generally happens that an improvement which cuts the labor and, hence, the cost of an article in half, multiplies the demand by at least four, so that twice as many men are needed for production, and not half as many. The opportunities for electronic control of industrial processes are unlimited, and the research opportunities include new electronic devices, new types of motors with instantaneous speed and torque response, and new automatic processes for a wide variety of industries.

Higher and higher in the electronic frequency spectrum lies the alluring pioneer frontier of electronics. Some valuable products in this region have been discovered during the war, of which the most important is radio echo-location of objects. Research will be needed to adapt this war weapon to furnish eyes for airplanes. What lies beyond? Perhaps meteorological observations, with waves which are reflected from clouds and raindrops, or absorbed by water vapor are the next advance. This would give us an additional instrument for the study of weather, the number one problem in air travel and in farming. Higher still in frequency lie the means for study of chemical bonds with waves whose frequencies are the same as the natural oscillations of molecules. These objectives are the treasures which we shall seek, which will serve as justification for the adventure. We shall, if fortunate, discover something much greater.

Atomic Energy. Shortly before the war it was discovered that certain atomic nucleuses become unstable when struck by neutrons and in exploding release an amount of energy greater than that which they received from the bombarding neutron. Thus was suggested the breath-taking possibility of obtaining useful power from the disintegration of atoms. Physicists the world over are impatient for the war to end so that they can get back to this research. No gold rush ever held greater enchantment, or greater potential disappointment. The use which we visualize is power to replace coal, and the odds are strongly against us. But the stakes are so high that the research gamble would be justified, even if this were the only possible reward. The prospect of other rewards, at present unsuspected, makes the adventure irresistible. No electrical laboratory with funds and facilities can afford not to have a part in this research.

THE MOST VALUABLE RESULTS OF RESEARCH CANNOT BE PREDICTED

The problems discussed herein are only a small fraction of those awaiting research, and they are merely things that can be seen, that exist already in imagination. They are starting points for research, the objectives which justify it and serve as a basis for its budgets. But, if history repeats itself, the most valuable results will be discoveries made along the road. Often their value is not appreciated at the time. For example, the whole thyratron industry is founded on a chance observation of the behavior of a thoriated tungsten cathode in a gas discharge. It was observed that the filament *did not lose* its monatomic coating of thorium in a gas discharge, when the voltage drop was less than 22 volts, whereas the coating was quickly knocked off at higher voltages. This was the first time that freedom from disintegration had been observed in a low-pressure gas discharge, and it soon led to the development of long-lived gas-discharge devices. But at the time that the observation was made, the rapid disintegration at higher voltages seemed more important than its absence at low voltages.

Such observations become starting points for new research explorations, and so the horizon expands. With each new discovery the thrill of adventure grows, and the desire to pioneer and to risk increases. It is this spirit which our country needs to combat depression and unemployment. It is an infectious spirit, which is caught and propagated in co-operative research groups, and from them can spread through industry and society.

It goes without saying that we are talking about good research, by qualified men with proper backing. It is as easy to throw money away in pseudo-research as on any other bad venture, and there are laboratories in which the prevailing spirit is not that of adventure but of pessimism and defeatism. The spirit of science cannot be mobilized; but it can grow, and there are good research organizations in this country which can serve as nucleuses for such growth. These research centers may be expanded, and new ones may be started with due caution in the choice of leaders and with patience to allow healthy growth.

Such a growth of scientific research, with men of character, imagination, and enthusiasm added as fast as they are available and infected with this spirit of progress and adventure, may leaven our whole economic structure and act as an antitoxin to the dreaded epidemics of depression and unemployment.

REFERENCES

1. Report of National Research Council to National Resources Planning Board, 1942; II, page 122 (survey by Joseph V. Sherman, Fiduciary Counsel, Inc., New York, N. Y.).

2. Markets After the War, **S. Morris Livingston**, United States Department of Commerce, 1943.

In this X-ray crystal irradiation unit developed by the North American Philips Company in conjunction with the United States Army Signal Corps, the frequency of crystal wafers in the six-to-eight-megacycle-per-second range can be changed from two to three kilocycles per second total. The change is permanent through any probable temperature range

INSTITUTE ACTIVITIES

Program Announced for Winter Technical Meeting, January 22–26, 1945

A program comprised of many wartime developments with interesting postwar applications has been arranged for the AIEE winter technical meeting to be held in New York, N. Y., January 22–26, 1945. Headquarters for the meeting will be in the Engineering Societies' Building. Sessions and conferences closely related to the war effort are as follows: electric welding, industrial control, industrial power applications, influence of aircraft environment on electrical design, aircraft electric apparatus and utilization, aircraft electricity, wartime distribution systems, high-frequency cables, and high-frequency dielectric heating.

JOINT IRE-AIEE SESSION

Continuing the custom of recent years a joint IRE–AIEE session will be held in the Engineering Auditorium on Wednesday evening, January 24. A feature address, "The Navy Electronics Program and Some of Its Past, Present, and Future Problems," by Captain J. B. Dow, United States Navy, will be of interest to a great many members of both organizations.

EDISON MEDAL PRESENTATION

Another feature of the joint session this year will be the presentation of the AIEE Edison Medal to E. F. W. Alexanderson "for his outstanding inventions and developments in the radio, transportation, marine, and power fields." Doctor Alexanderson is consulting engineer with the General Electric Company, Schenectady, N. Y., and a member for life.

SMOKER

The smoker will be held Tuesday evening, January 23, at the Hotel Commodore. This location affords an opportunity for recreation and for getting together with friends amidst pleasant surroundings. Insofar as possible all of the features of this affair will be provided as in previous years. Tickets, including the dinner and show, will be six dollars per person, including tax. Tables for ten can be reserved by advance payment. Checks should be made out to "Special Account, National Secretary, AIEE."

THEATER TICKETS

Every effort is being made to have choice tickets available for the best shows. These are being reserved for the eveningsof Wednesday, January 24, and Thursday, January 25. Preference will be given to requests from out-of-town members. Members desiring tickets for specific performances on these or other dates may write to Institute headquarters enclosing checks made out to "Special Account, National Secretary, AIEE. The theater-ticket committee will do its utmost to take care of such requests.

A limited number of seats are now available for "Oklahoma," "Song of Norway," "Voice of the Turtle," and "Bloomer Girl." Ticket prices follow:

Song of Norway	$6.00
Voice of the Turtle	4.20
Oklahoma	4.80
Bloomer Girl	5.40

REGISTRATION AND HOTELS

Members who have received an advance registration card by mail should fill in and return the card promptly. Upon arrival at the meeting members who registered in advance should not fill in another card, but badges should be obtained. A registration fee of two dollars will be charged to all nonmembers except Enrolled Students and the immediate families of members.

Hotel reservations should be made by writing directly to the hotel preferred.

COMMITTEES

The personnel of the 1945 winter technical meeting committee, which is making the arrangements, is as follows: J. F. Fairman, *chairman;* F. A. Cowan, W. S. Hill, M. D. Hooven, A. E. Knowlton, C. S. Purnell, C. C. Whipple, R. J. Wiseman.

W. R. Van Steenburgh is chairman of the smoker committee and C. S. Purnell of the theater and broadcast tickets committee.

JOINT MEETING OF HKN AND TBII

Vlademir Karapetoff will give a nonmathematical discussion of "Fundamentals of Relativity" at a joint meeting of Eta Kappa Nu and Tau Beta Pi on Monday evening, January 22. Ladies and guests will be welcome.

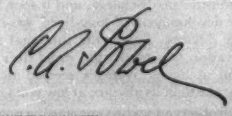
Greetings from the President——

I extend to each of you my personal greetings at the beginning of this new year, which promises to be a momentous one for our nation—for all nations.

The Institute has reason to be proud of its performance during the past year. It has contributed notably to winning the war through its committee work; through the setting up of special standards; through conferences devoted to the solution of many technical problems brought about by the war; and particularly through its many members who have joined the Armed Forces and provided them with a large corps of men with specialized training.

The work is, however, far from finished. With the likelihood of cessation of hostilities in Europe, the Institute and other technical and scientific societies must participate in the all-important work of reorienting our domestic and international economy. We are hopeful that the Government will recognize the past accomplishments of the engineering profession and the assistance that it might render at the peace table and subsequently.

I thank you for your loyal support of the Institute and express my sincere hope that the coming year will bring you the utmost happiness and prosperity.



AIEE Board of Directors Approves Protest on Army–Navy Fee Limit

Endorsement of the resolution adopted by the American Society of Civil Engineers and recommended by the Joint Conference Committee of the Founder Societies protesting the limitation of $25 per day on consulting fees imposed by the Army and Navy Appropriation Acts enacted in July 1943 by Congress recently was announced by AIEE board of directors. The ASCE resolution favors raising the maximum fee to $100 per day on the grounds that the present compensation is wholly inadequate and cannot be expected to command the services of men of the highest qualifications. The text of the resolution follows:

1. *Whereas*, the board of direction of the American Society of Civil Engineers has given consideration to the terms of Congressional Acts which establish $25 per day as compensation for the services of consulting engineers in connection with the design and construction of Federally sponsored projects, and

2. *Whereas*, such compensation is recognized as being wholly inadequate for the character of services required, and

3. *Whereas*, the best interests of the country cannot be served by such requirement for the reason that properly qualified professional engineers of high ability and established reputation cannot be expected to offer their services on such a basis,

4. *Now, therefore be it resolved* that the board of direction of the American Society of Civil Engineers, assembled in session on this tenth day of October 1944, protest the currently established fees and recommend that in future legislation a maximum fee of at least $100 per diem be provided as a basis of compensation for the services of consulting engineers, and

5. *Be it further resolved* that copies of this resolution be furnished to members of Congressional Committees who may be concerned with the framing of appropriate legislation from time to time.

Tentative Winter Technical Meeting Program

Monday, January 22

9:30 a.m. Power Generation

45-4. Evaluation of Electric-Distribution Losses in Terms of Generating-Station-Capacity Investment. **Mario Mortara,** consulting engineer

45-9. Use of Dielectric-Absorption Tests in Drying Out Large Generators. **H. C. Marcroft,** Pennsylvania Water and Power Company

45-34. Frequency Changers—Characteristics, Applications, and Economics. **S. B. Crary, R. M. Easley,** General Electric Company

45-36. Proposed Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Turbogenerators. Joint Committee on Turbogenerators, AIEE–ASME

9:30 a.m. Temperature Measurements and Standards

45-33. Investigation of Hot-Spot Temperatures in Integral-Horsepower Motors. **L. E. Hildebrand, B. M. Cain, F. D. Phillips,** General Electric Company; **W. R. Hough, J. G. Rosswog,** Reliance Electric and Engineering Company; **C. P. Potter,** Wagner Electric Corporation

45-32. Investigation of Hot-Spot Temperatures in Fractional-Horsepower Motors. **L. H. Hirsch,** Century Electric Company; **R. F. Munier,** Emerson Electric Manufacturing Company; **M. L. Schmidt, L. W. Wightman,** General Electric Company; **J. S. Himebrook,** Master Electric Company; **T. C. Lloyd, O. G. Coffman,** Robbins and Myers, Inc.; **C. P. Potter,** Wagner Electric Corporation

45-37. Temperature Limits and Abstracts of Present Standards and Practices for Stationary-Contact Surfaces. AIEE subcommittee on conduction in stationary contact surfaces

9:30 a.m. Basic Sciences

45-38. Power Geometry of General Transmission Systems. **William Altar,** Westinghouse Electric and Manufacturing Company

45-39. Formulas for Calculating Temperature Distribution in Transformer Cores and Other Electric Apparatus of Rectangular Cross Section. **Thomas J. Higgins,** Illinois Institute of Technology

45-1. Two-Phase Co-ordinates of a Four-Phase Network. **E. W. Kimbark,** Northwestern University

45-40. Transient Response of Controlled-Rectifier Circuits. **P. T. Chin, G. E. Walter,** General Electric Company

2:00 p.m. Conference on Central-Station Auxiliaries

The purpose of this conference is to obtain an informal cross section of existing practice and also to get an expression of ideas in regard to the important subject of station auxiliaries and related problems. The following engineers are expected to participate:

J. B. McClure, General Electric Company

W. R. Brownlee, Commonwealth and Southern Corporation

J. A. Elsi, Commonwealth and Southern Corporation

H. N. Muller, Westinghouse Electric and Manufacturing Company

J. H. Harlow, Philadelphia Electric Company

V. E. McCallum, Commonwealth Edison Company

C. W. Taylor, Sargent and Lundy

R. P. Crippen, Ebasco International Corporation

Many others representing the users, designers, and the manufacturers of equipment have expressed a desire to discuss the subject. Topics anticipated for conference presentations are as follows: power requirements, selection of voltages, type and speed of motors, reliability of power-supply systems, control, and switching and protection of auxiliaries.

2:00 p.m. Electrical Machinery

45-41. Standards and Insulation Characteristics of Oil-Insulated Transformers. **F. J. Vogel,** Illinois Institute of Technology

● **PAMPHLET** reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.

● **ABSTRACTS** of most papers appear on pages 31–9 of this issue and pages 447–8 of the December 1944 issue.

● **PRICES** and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers are available in pamphlet form.

● **COUPON** books in five-dollar denominations are available for those who may wish this convenient form of remittance.

● **THE PAPERS** regularly approved by the technical program committee ultimately will be published in "Transactions;" many will appear in "Electrical Engineering."

45-42. Measurements of Stray-Load Loss in Induction Motors. **D. H. Ware,** General Electric Company

45-12. Measurement of the Subtransient Impedances of Synchronous Machines. **Gordon F. Tracy,** University of Wisconsin; **W. F. Tice,** Barber-Colman Company

45-2. Damping Effect of D-C Marine Propulsion Motors on Vibrations Produced in Drive Shafts by Large Propellers. **Bernard Litman,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Statistical Methods Applied to Standards

CP.* Fundamental Statistical Tools for Controlling Quality. **J. Manuele, Casper Goffman,** Westinghouse Electric and Manufacturing Company

CP.* Statistical Methods Applied to Insulator Development and Manufacture. **J. J. Taylor,** Ohio Brass Company

CP.* Demerit Schedules of Underwriters' Laboratories. **M. M. Brandon,** Underwriters' Laboratories

CP.* Application of Quality Control to Resistance Welding. **R. S. Inglis, R. P. McCants, L. S. Hobson,** General Electric Company

Tuesday, January 23

9:30 a.m. Circuit Breakers

45-43. Field Tests and Performance on Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air-Blast. **Philip Sporn, H. P. St. Clair,** American Gas and Electric Service Corporation

45-44. A Three-Cycle 3,500-Megavolt-Ampere Air-Blast Circuit Breaker for 138,000-Volt Service. **H. L. Byrd, B. S. Beall, III,** General Electric Company

45-45. A High-Capacity High-Voltage Three-Cycle Oil Circuit Breaker. **H. L. Byrd, E. B. Rietz,** General Electric Company

45-46. The Next Step in Interrupting Capacity—5,000,000 Kva. **A. W. Hill, W. M. Leeds,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Electric Welding

CP.* Modern Developments in the Use of Arc Welding. **W. J. Conley,** The Lincoln Electric Company

*CP: Conference paper; no advance copies are available; not intended for publication in *Transactions*.

45-29. Analysis of Arc-Welding Reactors. **C. M. Wheeler,** General Electric Company

45-48. The Power-Distribution Problem in Arc Welding. **H. W. Pierce, G. E. Smith,** New York Shipbuilding Corporation

45-28. Power Supply for A-C Arc Welding. **A. U. Welch, R. F. Wyer,** General Electric Company

9:30 a.m. Machinery Insulation

45-49. Insulation-Resistance and Dielectric-Absorption Characteristics of Large A-C Stator Windings. **J. S. Askey, J. S. Johnson,** Westinghouse Electric and Manufacturing Company

45-23. The Application of Silicone Resins to Insulation for Electric Machinery. **J. deKiep, L. R. Hill, G. L. Moses,** Westinghouse Electric and Manufacturing Company

45-30. Organosilicon Compounds for Insulating Electric Machines. **T. A. Kauppi,** Dow Corning Corporation; **G. L. Moses,** Westinghouse Electric and Manufacturing Company

45-50. Rating of High-Temperature Induction Motors. **P. L. Alger, H. A. Jones,** General Electric Company

2:00 p.m. Meeting of Committee on Safety

The committee on safety will hold jointly a committee meeting and a technical conference. Invitation to attend is extended to all members and guests interested in the work of this committee.

2:00 p.m. Mercury-Arc Rectifiers and Protection

45-20. Arc-Backs in Rectifier Circuits—Artificial Arc-Back Tests. **R. D. Evans, A. J. Maslin,** Westinghouse Electric and Manufacturing Company

45-51. Rectifier Fault Currents. **C. C. Herskind, H. L. Kellogg,** General Electric Company

45-52. Anode-Circuit-Breaker Design and Performance Criteria. **E. W. Boehne, W. A. Atwood,** General Electric Company

45-53. Voltage and Current Relations for Controlled Rectification With Inductive and Generative Loads. **K. P. Puchlowski,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Protective Devices

45-54. Improved Fault Protection for Rural Distribution Systems. **A. Van Ryan,** Kyle Corporation

45-8. Graphical Method of Calculating Fault Currents on Rural Distribution Systems. **F. W. Linder,** Rural Electrification Administration

45-55. Rectifier Relay for Transformer Protection. **E. L. Michelson,** Commonwealth Edison Company

45-56. New Solenoid Mechanism for Magne-Blast Breaker. **B. W. Wyman, J. H. Keagy,** General Electric Company

45-57. Nine Years' Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines. **Philip Sporn, C. A. Muller,** American Gas and Electric Service Corporation

2:00 p.m. Electric Machinery

45-16. Inherent Errors in the Determination of Synchronous-Machine Reactances by Test. **C. Concordia, F. J. Maginniss,** General Electric Company

45-22. Damping and Synchronizing Torques of Power Selsyns. **C. Concordia, Gabriel Kron,** General Electric Company

45-14. Transient Electrical Torques of Turbine Generators During Short Circuits and Synchronizing. **H. S. Kirschbaum,** Westinghouse Electric and Manufacturing Company

45-15. Determination of Transient Shaft Torques in Turbine Generators by Means of the Electrical—Mechanical Analogy. **G. D. McCann, C. E. Warren, H. E. Criner,** Westinghouse Electric and Manufacturing Company

6:30 p.m. Smoker at Hotel Commodore

Tentative Winter Technical Meeting Program (Continued)

Wednesday, January 24

10:00 a.m. General Session

Feature talk on a timely topic that will be of interest to many members. To be announced later.

2:00 p.m. Cables and Corrosion

45-58. The Dielectric Strength and Life of Impregnated Paper—IV. **J. B. Whitehead, J. M. Kopper,** The Johns Hopkins University

45-59. Electrolysis and Corrosion of Underground Power-System Cables. **I. J. Gorman,** Consolidated Edison Company of New York, Inc.

45-60. Galvanic Corrosion of Soil Waters. **H. S. Phelps, F. Kaho,** Philadelphia Electric Company

45-61. Study of A-C Sheath Currents and Their Effect on Lead-Cable Sheath Corrosion. **C. M. Shorer,** Pennsylvania Water and Power Company; **K. J. Granbois,** Safe Harbor Water Power Corporation

2:00 p.m. Industrial Control

45-27. Variable-Unbalanced-Voltage Control. **W. R. Wickerham,** Westinghouse Electric and Manufacturing Company

45-62—ACO.** Principles of Grid Control for Thyratrons. **P. H. Chin, E. E. Moyer,** General Electric Company

45-64. An Interval Timer for Arc Duration. **J. S. Quill,** General Electric Company

2:00 p.m. Instruments and Measurements

45-24. Orthomagnetic Bushing Current Transformer for Metering. **A. Boyajian, G. Camilli,** General Electric Company

45-19. A Modulated-Frequency System of Telemetering. **H. E. Renfro, A. P. Peterson,** Control Corporation

45-65. Dynamic Measurements on Electromagnetic Devices. **E. L. Norton,** Bell Telephone Laboratories, Inc.

45-66. A Portable Instrument for Measuring Insulation Resistance at High Voltage. **F. W. Atkinson, R. B. Taylor,** The Takk Corporation

2:00 p.m. Conference on Relay Protection of Generators

8:00 p.m. Joint IRE–AIEE Session

Edison Medal presentation
Address: The Navy Electronics Program and Some of Its Past, Present, and Future Problems. Captain J. B. Dow, United States Navy

Thursday, January 25

9:30 a.m. Lightning

45-67. Impedances Seen by Relays During Power Swings With and Without Faults. **Edith Clarke,** General Electric Company

45-18. Lightning Investigation of 132-Kv System of American Gas and Electric Company. **I. W. Gross, G. D. Lippert,** American Gas and Electric Service Corporation

45-26. Lightning Investigation on Transmission Lines—VIII. **W. W. Lewis, C. M. Foust,** General Electric Company

9:30 a.m. Communication

45-68. A Comparison of the Amplitude-Modulation, Frequency-Modulation, and Single-Side-Band Systems for Power-Line Carrier Transmission. **R. G. Cheek,** Westinghouse Electric and Manufacturing Company

45-69. The Resistance-Coupled Amplifier. **L. G. Cowles,** The Texas Company

45-70. The Tapered Transmission Line. **J. W. Milnor,** Consulting Engineer

**ACO: Advance copies only available; not intended for publication in *Transactions*.

9:30 a.m. Industrial Power Applications

45-47. Tracer-Controlled Position Regulator for Propeller Milling Machine. **C. R. Hanna, W. O. Osbon,** Westinghouse Electric and Manufacturing Company; **R. A. Hartley,** Adel Precision Products Corporation

45-71. Application of Electric Equipment for Propeller Milling Machine. **H. E. Morton,** Morton Manufacturing Company; **O. G. Rutemiller,** Crosley Corporation

45-35. Design of Sealed Ignitron Rectifiers for Three-Wire Service. **M. M. Morack,** General Electric Company

45-72. Application of Capacitors for Power-Factor Improvement of Induction Motors. **W. C. Bloomquist, W. K. Boice,** General Electric Company

9:30 a.m. Aircraft Electric Apparatus and Utilization

45-3. Speed-Control System for an Aircraft Cabin-Supercharger Drive. **F. W. Godsey, J. D. Miner, Jr., O. C. Walley,** Westinghouse Electric and Manufacturing Company

45-81. The Amplidyne Generator Applied to Speed-Controlled Electric Gun Turrets for Aircraft. **L. A. Zahorsky,** General Electric Company

45-82. 400-Cycle Inverters for Military Aircraft. **C. P. Hayes, L. L. Ray,** General Electric Company

45-6. Aircraft Illumination. **W. W. Davies,** United Air Lines, Inc.

2:00 p.m. Supervisory Control and Stability Improvement

45-77. The Combination of Supervisory Control With Other Functions on Power-Line Carrier Channels. **R. C. Cheek, W. A. Derr,** Westinghouse Electric and Manufacturing Company

45-7. Supervisory Control for New Chicago Subway. **W. A. Derr,** Westinghouse Electric and Manufacturing Company; **C. J. Buck,** Chicago Rapid Transit Company; **J. A. Stoos,** Department of Subways and Superhighways, City of Chicago

45-78. Power-Line Carrier Channels. **M. J. Brown,** Westinghouse Electric and Manufacturing Company

45-13. Improving Stability by Rapid Closing of Bus-Tie Switches. **E. W. Kimbark,** Northwestern University

2:00 p.m. Land Transportation

45-31. Compressed-Air Circuit Breakers in A-C Railway Service. **H. M. Wilcox, D. C. Harker,** Westinghouse Electric and Manufacturing Company

45-17. Mercury-Arc Rectifiers for Railroads. **S. S. Watkins,** Gibbs and Hill, Inc.

45-10. Electrification and Signaling of the Canadian National Railways' Terminal at Montreal, Canada. **R. G. Gage,** Canadian National Railways

45-11. Grounding of Circuits on Self-Propelled Vehicles. **D. D. Ewing,** Purdue University

2:00 p.m. Industrial Power Applications

45-25. The Design of Bus-Bar Industrial Distribution Systems: an Epitomization of Available Data. **T. J. Higgins,** Illinois Institute of Technology

45-21. Dodge Chicago Plant's Electric-Power-Distribution Scheme With Airplane-Engine-Testing Power Recovery. **E. L. Bailey,** Chrysler Corporation

45-79. Modern Electric-Power-Distribution Ideas as Applied in a Large War Plant. **R. H. Kaufmann,** General Electric Company; **N. A. Kieb,** Pratt and Whitney Aircraft Corporation

45-80. Induction Heating of Moving Strip. **R. M. Baker,** Westinghouse Electric and Manufacturing Company

2:00 p.m. The Influence of Aircraft Environment on Electrical Design

45-73. Electrolytic Corrosion—Methods of Evaluating Insulating Materials Used in Tropical Service. **B. H. Thompson, K. N. Mathes,** General Electric Company

45-5. Simulated-High-Altitude Testing of Aircraft Ignition Cables and Connectors. **H. H. Race, A. M. Ross, Jr.,** General Electric Company

45-74. Preferred Practices for Electric Control Devices for Aircraft. **F. W. Hottenroth, Jr.,** General Electric Company

45-75. Effect of Altitude on Temperature Rise of Aircraft Transformers. **V. M. Montsinger,** General Electric Company. Presentation by title

45-76. Vibration Insulation and Structural Rubber. **J. A. Connon,** United States Rubber Company. Presentation by title

Friday, January 26

9:30 a.m. Conference on Wartime Practices on Distribution Systems and Their Effect on System Operation and Future Designs

This conference is being sponsored by the committee on power transmission and distribution to ascertain the effect of wartime restrictions on power-distribution-system operating and design practices. The committee anticipates a free discussion, representative of present-day thinking, which might assist in establishing more clearly the probable effects of this thinking upon future distribution-system, substation, and circuit designs and upon operating experience. Subjects tentatively selected for discussion, upon which data are being prepared for presentation, are:

CP.* Analysis of Availability of Equipment as Effected by Prearranged Maintenance Requirements and Capacity Limitations Resulting From Equipment

CP.* Analysis of Customer-Service Interruptions as a Means of Determining Acceptability of Designs for Methods of Supply

CP.* Limiting Effect of Auxiliary Equipment, Such as Connectors and Clamps, Upon the Ratings of Overhead Conductors

CP.* Tendencies Toward Changes in Design and Operating Practices as a Result of Recent Experiences

This conference will be informal, and any related subjects can be developed during the discussion.

9:30 a.m. Conference on High-Frequency Cables

This conference is sponsored by the committee on communication with the co-operation of the Army–Navy *RF* cable co-ordinating committee. The subject will be the design and manufacture of radio-frequency solid-dielectric cables. Topics to be discussed will include requirements and design criteria for cable structures, properties and manufacture of polyethylene, extrusion and manufacture of flexible cables, and methods of testing cables through the whole spectrum up to several thousand megacycles. The conference will be conducted under the general guidance of Lieutenant Commander John H. Neher, United States Naval Reserve, with several qualified topic leaders. It is expected that many members will wish to contribute to the discussion, and it is hoped also that a co-ordinated conference report may be made available later.

9:30 a.m. Conference on High-Frequency Dielectric Heating

2:00 p.m. Conference on Industrial System and Apparatus Voltage Ratings

This conference will discuss system and apparatus voltage ratings from the standpoint of industrial user. Participating:

Howard P. Seelye, Detroit Edison Company
T. C. Duncan, Consolidated Edison Company of New York, Inc.
Don Beeman, General Electric Company
F. W. Cramer, Carnegie-Illinois Steel Company
K. K. Falk, Bendix Aviation Corporation
R. T. Woodruff, Aluminum Ore Company
John M. Webb, Eli Lilly Company

The committee on industrial power applications believes this symposium will do much to clarify the problem as it affects industrial users of electric apparatus and at the same time present an opportunity for the presentation of the viewpoints of the utilities and the manufacturers.

2:00 p.m. Conference on Air Transportation

2:00 p.m. Conference on Domestic and Commercial Applications

Expense Awards Established From Members-for-Life Fund

Utilization of the member-for-life fund to defray the expenses of District Branch paper prize winners to the summer meeting where they would present their papers has been announced by the standing committee in charge of the administration of the fund. These annual member-for-life awards are to be established as follows:

1. The payment of the expenses of five District Branch paper prize winners to the summer technical meetings of the Institute to present their papers on the regular technical program of the meeting.

2. The awards to be available to the even-numbered Districts for the summer technical meeting held in the even-numbered years and to the odd-numbered Districts in the odd-numbered years.

3. The expenses to be paid in the form of an allowance of nine cents per mile one way from the award winner's home town to the place of the summer technical meeting plus a reasonable allowance per day for the official duration of the meeting.

The member-for-life fund was set up at the January 1944 meeting of the AIEE board of directors by the approval of recommendations that the voluntary dues payments made by members-for-life be kept in a separate fund in the custody of the treasurer of the Institute. This fund is to be used only for such special purposes as will aid the objectives of the Institute, these purposes to be determined by a designated administrative committee.

The committee's decision to use this income for the establishment of annual member-for-life awards is applicable to the 1945 and 1946 summer meetings only. It will be determined from the experience gained whether or not to continue utilizing the fund for this purpose.

AIEE Nominating Committee for 1944–45 Announced

The national nominating committee of the AIEE, in accordance with the Institute's bylaws, will meet during the winter technical meeting January 22–26, 1945, in New York, N. Y., to nominate candidates for national offices to be voted on by the membership in the spring of 1945. Members of the national nominating committee are as follows:

Representing the board of directors

P. L. Alger, General Electric Company, Schenectady, N. Y.

R. T. Henry, Buffalo Niagara Electric Corporation, Buffalo, N. Y.

T. G. LeClair, Commonwealth Edison Company, Chicago, Ill.

S. H. Mortensen, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

C. W. Ricker, Tulane University, New Orleans, La.

Alternates:

J. F. Fairman, Consolidated Edison Company of New York, Inc., New York, N. Y.

N. E. Funk, Philadelphia Electric Company, Philadelphia, Pa.

Representing the ten geographical Districts

1. F. S. Bacon, Jr., Westinghouse Electric and Manufacturing Company, Boston, Mass.

2. F. J. Chesterman, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

3. M. D. Hooven, Public Service Electric and Gas Company, Newark, N. J.

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 22–26, 1945

North Eastern District Meeting
Buffalo, N. Y., April 25–26, 1945

Summer Technical Meeting
Detroit, Mich., June 25–29, 1945

4. J. D. Harper, Aluminum Company of America, Alcoa, Tenn.

5. J. E. Hobson, Illinois Institute of Technology, Chicago, Ill.

6. I. M. Ellestad, Northwestern Bell Telephone Company, Omaha, Nebr.

7. M. C. Hughes, Agricultural and Mechanical College of Texas, College Station, Tex.

8. F. C. Lindvall, California Institute of Technology, Pasadena, Calif.

9. Joseph Hellenthal, Puget Sound Power and Light Company, Seattle, Wash.

10. D. G. Geiger, Bell Telephone Company of Canada, Toronto, Ont.

Alternate:

6. M. L. Burgess, Westinghouse Electric and Manufacturing Company, Omaha, Nebr.

Committee Will Award Fortescue Fellowship for 1945–46

The normal procedure for awarding the Fortescue fellowship which has been hampered by the war's removing most of the eligible candidates from scholastic pursuits since 1942 will be resumed for the college year 1945–46. Application blanks are being mailed to accredited schools and also may be obtained from the AIEE National Secretary.

Established in 1940, the award was made only once when it went to Norman Z. Alcock, Kingston, Ontario, Canada, for the year 1940–41, before it was suspended because of the war. The fellowship of $500 or more was made possible through a trust fund set up by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., under the sponsorship of the AIEE as a memorial to Charles LeGeyt Fortescue (A '03, F '21) in recognition of his contributions to the electric-power industry.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE winter technical meeting, New York, N. Y., January 22–26, 1945, and will be distributed in advance-pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract, or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Air Transportation

45-73—Electrolytic Corrosion—Methods of Evaluating Insulating Materials Used in Tropical Service; *B. H. Thompson, K. N. Mathes (M '43). 20 cents.* The selection of insulating materials to guard against electrolytic corrosion has become increasingly important, as the use of electric devices in the tropics has increased. Moisture conditions in the tropics are described, and means for producing such conditions in the laboratory are considered. The visual, corrosion-current, and water-extract-conductivity methods for studying electrolytic corrosion are described. Typical results for a number of different materials are given.

45-74—Preferred Practices for Electric Control Devices for Aircraft; *F. W. Hoitenroth, Jr. 15 cents.* This paper points out the need for design standards for electric equipment used on aircraft. It suggests that the AIEE set up standards of preferred practices for electric control equipment for planes and includes a sample set of standards as a starting point for discussion. These standards include such items as: temperature rise of coils, vibration tests, and creepages. The paper also describes certain design features which have been found particularly advantageous under the special conditions encountered on planes. It indicates that double-break contacts are especially suited for high-altitude operation on 24-volt systems and shows a close co-ordination between single-break contact ratings at 12 volts direct current and double-break ratings at 24 volts direct current.

45-81—The Amplidyne Generator Applied to Speed-Controlled Electric Gun Turrets for Aircraft; *L. A. Zahorsky (A '42). 20 cents.* A particular type of Amplidyne generator which develops readily controlled power for aircraft machine-gun turrets has attained widespread usage in the field of aircraft utilizing electric gun turrets. The functions of the turret power drive, a brief description of the Amplidyne, and the details of the Amplidyne characteristics measured in terms of the turret operation are of value in understanding the purpose of the Amplidyne generator. Some of the advantages of separating the Amplidyne characteristics from those of the entire turret performance in design, trouble shooting, and in application are discussed. A working specification for the Amplidyne, in terms of the turret control system, and another set of specifications for the Amplidyne alone are presented in conclusion.

45-82—400-Cycle Inverters for Military Aircraft; *C. P. Hayes (A '41), L. L. Ray (A '44). 15 cents.* Modern military aircraft require an a-c power supply for radio, radar, gyro compasses, and other control equipment. The a-c power usually is obtained from conversion equipment which converts the d-c supply of the engine generators and batteries to alternating current. This paper discusses the type of inverters and describes a 1,500 volt-ampere inverter which the authors designed. This discussion includes details of frequency and voltage regulators, as well as improvements in ventilation and brush life. Illustrations of several types of inverters, speed regulators, and voltage regulators are included.

45-75—Effect of Altitude on Temperature Rise of Aircraft Transformers; *V. M. Montsinger (F '29). 15 cents.* As aircraft transformers are required to operate at ex-

tremely high altitudes, it is important to know how changes in the air density affect their temperature rise. It is pointed out that the effect of altitude on temperatures can vary as much as 2.5:1, depending on the nature of the cooling surfaces which govern the percentages of loss by radiation and by connection. If these percentages are known (at sea level), it should be possible to predetermine the effect of altitude on any design of transformer, or on any kind of electric apparatus. A method for estimating the effect of altitude is given, and calculations obtained by the method are found to check quite closely the results of tests made on a two-kilovolt-ampere aircraft transformer under conditions representing a range in altitude from sea level to 40,000 feet.

45-76—Vibration Insulation and Structural Rubber; *J. A. Connan. 20 cents.* The purpose of this paper is to present to the engineer concerned with the protection of delicate equipment, a compilation of information on the fundamentals of mechanical vibrations and the properties of structural rubber. Vibration-insulation problems can be classified in two categories:

1. Problems involving the insulation from its surroundings of a unit originating vibration—an airplane engine, or instance.

2. Problems involving the protection of a delicate unit from external vibration—a radio set in an airplane is an example.

The paper then goes on to explain the fundamentals of mechanical vibration insulation by means of rubber mounting. This is divided broadly into two parts:

1. Fundamentals of the application of rubber mountings.

2. Structural characteristics of rubber as used in rubber mountings.

A number of practical formulas are included.

Basic Sciences

45-38—Power Geometry of General Transmission Systems; *William Altar (A '42). 20 cents.* A new geometrical relation between coexisting points in the complex charts of sender and receiver power is presented, with particular attention to circular contour lines and circle diagrams. To establish the relation, sender and receiver charts must be plotted in two separate co-ordinate systems of specified position. A pictorial interpretation in terms of a projective relation, not unlike a stereographic projection, also is offered. The results suggest a simple graphical procedure for the solution of transmission problems, not only as encountered in the field of power transmission but, also broadly speaking, wherever one deals with four-terminal networks. In the field of a-c machinery, for instance, a rigorous circle diagram for the induction-motor results as a direct consequence of the new approach.

45-59—Formulas for Calculating Temperature Distribution in Transformer Cores and Other Electric Apparatus of Rectangular Cross Section; *T. J. Higgins (A '40). 20 cents.* Formulas are derived for calculating the temperature distribution, maximum temperature, and average temperature in electric devices of rectangular cross section whereof geometric and surface conditions are such that the temperature distribution is substantially independent of the co-ordinate perpendicular to the plane of the cross section. This category comprises transformer cores, certain shapes of electric coils, bus bars, and other electrical apparatus. A rigorous solution is obtained for the following two-dimensional boundary-value problem in the mathematical theory of heat. To determine the expressions for the temperature distribution, maximum temperature, and average temperature in an infinite cylinder of rectangular cross section:

1. Wherein the heat developed per unit time per unit volume is a given linear function of the temperature.

2. Whereof the surface condition is that common to practice—at a point in the surface the difference between the temperatures of the surface and the immediately adjacent ambient medium is proportional to the outward normal derivative of the temperature.

3. This proportionality constant is taken differently on each of the four edges of the cross section.

4. The temperature distribution in the immediately adjacent ambient is assumed arbitrary, providing only that it be expressible in a generalized Fourier series over each edge of the cross section.

The desired expressions for this heat problem are obtained in the usual fashion: by combining particular solutions of the definitive differential equation, which are expressed as generalized double Fourier series with constant coefficients so determined that the boundary conditions are satisfied. Certain convenient special forms of the general expressions for T, T_m, and T_a are derived. Application of these formulas in calculating temperature distribution in electric apparatus stems from identification of the physical constants of a particular electric device with the corresponding constants of the general heat problem. Illustratively, the maximum temperature in a single-phase transformer is calculated and found to be almost identical with the measured experimental value. Calculation of the temperature distribution in toroidal electric coils is discussed concisely. Mention is made of other apparatus to which the formulas are applicable.

45-40—Transient Response of Controlled-Rectifier Circuits; *P. T. Chin (A '41), G. E. Walter (A '44). 25 cents.* Transients in circuits supplied by controlled rectifiers using gas- or mercury-vapor-filled electron tubes are found analytically by an extended superposition method. Loads containing resistance, inductance, and a counter electromotive force are studied, and results are obtained for both rectification and inversion. Examples are based on the half-wave biphase rectifier, and the appendix contains an analysis of a p-phase rectifier. The assumptions include constant circuit parameters, a fixed firing angle during transients, continuous-load current, and no leakage reactance in the supply transformer.

Communication

45-68—A Comparison of the Amplitude-Modulation, Frequency-Modulation, and Single-Side-Band Systems for Power-Line Carrier Transmission; *R. C. Cheek (A '42). 20 cents.* Many utility engineers interested in increasing the applications of power-line carrier on their systems are confronted with the difficult problem of finding space in an already crowded carrier-frequency spectrum for additional carrier channels. Other problems are introduced by the long distances and attendantly high attenuation and noise levels through which some carrier equipment must work. In general, a mere increase in the power of ordinary amplitude-modulated equipment is not a satisfactory solution to these problems. These facts have led to a consideration of the characteristics at power-line carrier frequencies of two fundamentally different systems of transmission, the frequency-modulation and the single-side-band systems. In this paper these systems are compared with the more familiar amplitude-modulation system on the basis of channel-width requirements, ability to work through high attenuation and noise levels, and other characteristics. The paper also discusses applications of the single-side-band system that are not possible with other systems in which a continuous carrier is transmitted.

45-69—The Resistance-Coupled Amplifier; *L. G. Cowles (A '31). 25 cents.* This paper presents practical methods for the coupling-circuit design of audio-frequency resistance-coupled amplifiers, and methods for determining the characteristics of a vacuum tube having a resistor in its external plate circuit. The material includes:

1. The classical solution of the coupling network rearranged for rapid calculations, with charts for determining the band width and coupling loss of the tuned amplifier.

2. A new method employing an equivalent circuit for determining the phase and amplitude characteristics of the resistance-coupled amplifier, including the narrow-band case without approximations.

3. A set of rules and charts for determining the electrode voltages and dynamic constants of a class-A vacuum tube having a resistor in its external plate circuit.

4. A simple circuit with which the dynamic constants and gain of a tube in resistance coupling can be measured, and with which it is easy to observe the gain and wave form obtainable with various tubes under different conditions of operation.

The methods presented in this paper can be applied easily and have been found to be of practical value in the design and application of the resistance-coupled amplifier.

45-70—The Tapered Transmission Line; *J. W. Milnor (F '30). 15 cents.* The computation of the performance of a telegraph or telephone transmission line in which the parameters vary along the line generally is quite involved. However, by restricting the variations to certain preferred plans of tapering, the computations become much simplified and do not exceed greatly in complexity those for the line with parameters constant along its length. Working formulas are included in the paper. The preferred plans are in fact those which would be chosen, when it is desired to provide most efficient transfer of energy.

Electric Machinery

45-12—Measurement of the Subtransient Impedances of Synchronous Machines; *G. F. Tracy (A '26), W. F. Tice. 15 cents.* A method of measuring the direct-axis and the quadrature-axis subtransient impedances of a synchronous motor or generator is described, in which three-phase voltages are

impressed on the machine at standstill, and appropriate instrument readings are taken from which the positive-sequence and the negative-sequence components of the voltages and currents are obtained. These values of symmetrical components then are substituted in a pair of formulas, which yield the desired impedances. The principal advantage of this new method is that it is not necessary to set the field structure of the machine in any specific position as in the present single-phase test, a requirement that may be troublesome in the case of large machines. Since the formulas contain a term involving the angle by which the pole axis is displaced from a reference phase, a simple test is described whereby this angle may be obtained.

45-16—Inherent Errors in the Determination of Synchronous-Machine Reactances by Test; *C. Concordia (M '37), F. J. Maginniss (A '43). 25 cents.* This paper presents the results of a study of proposed methods of measuring synchronous-machine transient and subtransient reactance. The utilization of the symmetrical and asymmetrical components of short-circuit current, as given by the AIEE Test Code, is discussed, and the effects of machine saliency and sequential closing are determined. As a result of this study, various modifications of the short-circuit test methods are proposed.

45-14—Transient Electrical Torques of Turbine Generators During Short Circuits and Synchronizing; *H. S. Kirschbaum (A '43). 15 cents.* During faults on turbine generators, and during synchronizing, the torques acting on the rotor of the machine may reach values of 15 or 20 times the rated torque of the machine. This is especially true of modern two-pole turbine generators. The problem of determining coupling and shaft stresses during such periods must proceed from a knowledge of the electric torque acting on the rotor. This paper presents a method of calculating the alternating and unidirectional torques which act on the rotor and a physical explanation of the origin of these components of torque.

45-15—Determination of Transient Shaft Torques in Turbine Generators by Means of the Electrical-Mechanical Analogy; *G. D. McCann (M '44), C. E. Warren (A '41), H. E. Criner. 15 cents.* A description is given of a new method and device (the mechanical transients analyzer) for solving a wide range of transient-vibration problems by the principle of electrical-mechanical analogy. This device has been applied to a study of the transient torques developed in the shafts of turbine generators during such disturbances as synchronization out of phase and electric-system faults. A general analysis is presented of the characteristics of the shaft torque under various system-fault conditions showing the relative effects of the resulting electric-rotor air-gap torques for a range of mechanical system constants. Illustrations also are given of the use of the analyzer for several other vibration problems.

45-22—Damping and Synchronizing Torques of Power Selsyns; *C. Concordia (M '37), Gabriel Kron (A '30). 25 cents.* When Selsyns are used as one of the power-amplifying stages of a control system, it is necessary to determine the hunting characteristics of these machines as affected by speed, load, oscillation frequency, and various design factors. As the direct calculation of these characteristics is difficult, this paper develops equivalent circuits that enable one to use the a-c network analyzer directly to measure the damping and synchronizing torques of Selsyns as affected by these various factors. Results of such studies made of specific balanced Selsyn systems are presented. Also, a principle of considerable generality is given stating the condition for stability of a power-Selsyn drive.

45-23—The Application of Silicone Resins to Insulation for Electric Machinery; *J. DeKleb (M '43), L. R. Hill, G. L. Moses (A '43). 20 cents.* Experience with the application of silicone resins is described, including laboratory tests on materials and coils, as well as laboratory tests on rotating apparatus. Practical problems regarding the use of these materials are discussed and recommendations made for obtaining an adequate high-temperature insulation. Thermal aging tests are reported and recommendations made as to tentative temperature limits for general rating and application purposes.

45-27—Variable-Unbalanced-Voltage Control for Wound-Rotor Motors; *W. R. Wickerham. 15 cents.* The application of variable unbalanced voltage to the primary winding of a polyphase induction motor represents a new departure in the design of control for this type of motor. The degree of unbalance varies automatically in response to speed, and the responsiveness is adjustable so that, compared to any single system now in use, a wider range of speed control through the complete load range is attainable. The speed-torque characteristics bear a considerable resemblance to those developed by a d-c motor operating with armature shunt. Abnormal input current, ordinarily associated with the application of unbalanced voltage to a motor, has been eliminated. Input current and motor-winding heating is only slightly in excess of that attendant on standard operation, and this is particularly true for the heavier loads and slower speeds.

45-30—Organosilicon Compounds for Insulating Electric Machines; *T. A. Kauppi (A '44), G. L. Moses (M '44). 20 cents.* The general problem of electrical insulation is reviewed in relation to silicone insulating materials. Silicone compounds are described and their chemical and physical characteristics discussed. Thermal stability and moisture resistance of silicone insulation are compared with that of conventional class-*A* and class-*B* insulation. Predictions are made as to the field of usefulness of silicones in electrical insulation. Recommendations are made for widespread investigation to evaluate the over-all advantages of this new type of insulation.

45-41—Standards and Insulation Characteristics of Oil-Insulated Transformers; *F. J. Vogel (M '41). 15 cents.* The strength of the insulation in transformers to resist various types of voltage stress is very important. The service and life of the transformer is partially dependent on the insulation strength, and in recognition of this fact standards for insulation strength have long been established. In the course of time, improvements have taken place in design, new applications have been created, and we have learned more about the nature of stresses which arise in service. Service conditions, too, probably will change in the future, which will require changes in insulation requirements. Therefore it is natural that gradual changes in the standards and additions to them have taken place, with the result that sometimes they are not entirely consistent. It is desired in this paper to point out some inconsistencies and propose certain changes in the standards which might be given consideration. Experience has shown that ability to withstand the applied 60-cycle test or 120-cycle induced test is no proof of a transformer's ability to withstand impulse tests. Therefore, it would be desirable to apply impulse tests to all transformers as a specified commercial test. It would be desirable to change the present tests, if any economies would result and if the testing procedure would be simplified. It is suggested that a three-microsecond, or a one-microsecond, or a steep-front impulse test might be substituted for the present applied or induced tests. Since the full-wave test is necessary, it should be retained. Probably it would be desirable also to retain a two times induced test as a last test for all transformer windings. If the one-microsecond test at the correct level were used, it would ensure the three-microsecond value without making another test.

45-32—Investigation of Hot-Spot Temperature in Fractional-Horsepower Motors; *L. H. Hirsch, R. F. Munier (A '32), M. L. Schmidt (M '43), L. W. Wightman, J. S. Himebrook (M '39), T. C. Lloyd (A '37), O. G. Coffman, C. P. Potter (F '29). 25 cents.* This paper is a summary of the data presented at a technical conference at the AIEE 1944 summer technical meeting, by the authors. It contains data comparing the temperature rise by thermometer, surface thermocouple, resistance, and embedded detector on open and totally enclosed, nonventilated, fractional-horsepower motors. It is hoped that this information will be useful to the AIEE on electrical machinery, the *C*-50 Committee of the American Standards Association, and the general engineering committee of the motor and generator section of the National Electrical Manufacturers Association, and that it will be used to make revisions which will bring the various temperature standards for fractional-horsepower motors into line.

45-33—Investigation of Hot-Spot Temperatures in Integral-Horsepower Motors; *L. E. Hildebrand (M '21), B. M. Cain (A '34), F. D. Phillips (M '35), W. R. Hough (M '41), J. G. Rosswog (A '41), C. P. Potter (F '29). 15 cents.* This paper is a summary of the data presented at a technical conference at the AIEE 1944 summer technical meeting, by the authors. It contains data comparing the temperature rise by thermometer, surface thermocouple, resistance, and embedded detectors in open, totally enclosed, nonventilated, and totally enclosed fan-cooled motors. It is hoped that this information will be useful to the AIEE committee on electrical machinery, the *C*-50 committee of

American Standards Association, and the general engineering committee of the motor and generator section of the National Electrical Manufacturers Association, and that it will be used to make revisions which will bring the various temperature standards for integral-horsepower motors into line.

45-42—Measurement of Stray-Load Loss in Induction Motors; *D. H. Ware. 15 cents.* In 1939, T. H. Morgan, W. E. Brown, and A. J. Schumer presented a paper proposing the reverse-rotation test for direct measurement of stray-load loss in induction machines. This test has proved to be accurate for small motors but is not accurate for large motors or high-speed motors of intermediate size and larger. This paper proposes a modification of Professor Morgan's method, and presents test data to show that this modification brings the reverse-rotation test into agreement with the input-output efficiency test for all sizes of motors.

45-49—Insulation-Resistance and Dielectric-Absorption Characteristics of Large A-C Stator Windings; *J. S. Askey (A'39), J. S. Jornson (A'36). 20 cents.* Insulation-resistance and dielectric-absorption characteristics are presented, which give a comprehensive picture of average and normal variations in the insulation characteristics of new large a-c stator windings. Temperature–insulation resistance characteristics are discussed. Considerations involved in the selection of formulas for safe minimum values of insulation resistance are discussed. Insulation characteristics are examined on a sufficiently large number of machines to give good statistical data.

45-50—Rating of High-Temperature Induction Motors; *P. L. Alger (F'30), H. A. Jones. 15 cents.* The advent of new high-temperature insulating materials, such as the silicones, gives new freedoms to the motor designer. It is probable, however, that factors other than insulation will limit the desirable motor temperature rise to values well below the endurance limits of these materials. It is, therefore, desirable to recognize that the size of an induction motor is measured electrically by its breakdown torque, and mechanically by the size of shaft and bearings, the temperature rise being only a secondary factor. Calculations are presented, based on idealized assumptions, which indicate that the optimum temperature rise for continuous rated induction motors is below 80 degrees centigrade, whatever the insulating materials used.

Electric Welding

45-28—Power Supply for A-C Arc Welding; *A. U. Welch (A'36), R. F. Wyer. 20 cents.* A-c arc welders may be divided into two general types—industrial and utility units. Industrial welders usually have built-in power-factor correction and operate at 0.75 to 0.85 power factor at full load. High-reactance transformer-type arc welders generally draw low inrush currents when energized. Transient overcurrents caused by starting a weld are usually less than 1.5 times the steady-state current. Duty factors run from 10 per cent to 50 or 60 per cent in manual welding, depending on the nature of the work. Diversity drastically reduces the maximum 15-minute demand, when more than four or five units are operating. Utility welders are designed for low kilovolt-ampere input. A suggested design would have a maximum 15-minute demand not exceeding 3.5 kva. A desirable design feature is strict limitation of the maximum obtainable output. A consumer supplied at 230 volts from an individual distribution transformer large enough to handle an electric range would not require additional transformer capacity to handle such a welder.

45-29—Analysis of Arc-Welding Reactors; *C. M. Wheeler. 15 cents.* The need and use of arc-welding reactors used for stabilizing the characteristics of single-operator d-c arc-welding sets are examined. The inductance useful in stabilizing welding arcs should be defined as the rate of change of flux linkages per ampere. This quantity, "welding inductance," is a function of current for iron-core reactors, one which may be evaluated from saturation curves and oscillographic tests. Through the study of performance requirements and the function of inductance in stabilizing welding arcs, synthesized reactor designs can take full advantage of electromagnetic material. They thus are tailored to the requirements of the user. A new arc-welding reactor embodying the principles of synthesis of design has a unique feature which at the same time improves the transient characteristics of the welding generator and makes possible a substantial reduction in size and weight.

45-48—The Power-Distribution Problem in Arc Welding; *H. W. Pierce, C. E. Smith (A'40). 20 cents.* The extent to which arc welding has contributed to the metal-fabricating industries in the present war has been well publicized, together with discussions of the problems of product design, materials, and operator training. Less has been written on the problem of power and power distribution in large-scale welding operations. This paper discusses the general principles and factors involved in the selection of power and the method of distribution with emphasis on flexibility to meet changing schedules and an expanding load. The application of these principles is illustrated in the selection of d-c power and a constant-potential distribution system for the ways in a shipyard with both a-c and d-c power from individual machines in the shops. The details of the distribution systems are fully described with illustrations.

Electronics

45-20—Arc-Backs in Rectifier Circuits—Artificial Arc-Back Tests; *R. D. Evans (F'40), A. J. Maslin (A'42). 30 cents.* This paper presents the results of an extensive investigation of arc-backs in rectifier circuits. The various factors affecting the arc-back current magnitudes and durations are reviewed. The nature of sympathetic arc-backs is discussed. Methods of making artificial arc-back tests are described, and relation to neutral arc-back conditions are compared. Results of extensive artificial arc-back tests made in the laboratory and the field are presented. These arc-back tests provided an opportunity for investigating the possibility of voltage surges, but no important voltage surges were observed.

45-35—Design of Sealed Ignitron Rectifiers for Three-Wire Service; *M. M. Morack (M'42). 15 cents.* Two-wire sealed ignitron rectifiers in the range of 75- to 1,000-kw capacity, at voltages between 250 and 600 volts direct current, have found wide application in industry during the war years. Rectifiers have met the need for efficient d-c power in general industrial, railway, mining, and electrochemical fields. The field of application is enlarged by the development of equipments for three-wire service, and it is the purpose of this paper to describe the design and operating characteristics of these units.

45-51—Rectifier Fault Currents; *C. C. Herskind (M'40), H. L. Kellogg (A'41). 20 cents.* The determination of fault currents in rectifier circuits is essential to the coordination of rectifiers, transformers, and protective switchgear to obtain the best design as regards economy and reliability. Methods are presented for determining the fault currents which flow in rectifier circuits during d-c short circuits and arc-backs. Three basic types of rectifier faults are considered in the analysis:

1. D-c short circuit.
2. Arc-back in a wye.
3. Arc-back with d-c feed.

Formulas are derived for fault current in these three cases. The analyses treat the general case where the rectifier-transformer secondary windings are interlaced and the reactance in the secondary leads is negligible so that all the circuit reactance may be considered to be located in the transformer primary winding and supply line. Typical oscillographic records of fault-current wave forms are presented together with a comparison of test and calculated values.

45-53—Voltage and Current Relations for Controlled Rectification With Inductive and Generative Loads; *K. P. Puchlowski (A'43). 25 cents.* The conventional methods of analytical treatment of power rectifiers do not offer any ready means for calculation of current and voltage outputs in the case where the firing point is delayed beyond a certain critical value, a condition very often met with in control systems. In addition the application of controlled rectifiers to d-c motors has created a number of special problems which are not answered by the conventional rectifier theory. This paper presents a generalized outline of analytical relations as well as a method of calculations of average values of steady-state output voltages for a polyphase rectifier system with delayed firing. Two types of load are considered: the *R-L* load and the one which includes a voltage-generating element in addition to *R* and *L* constants. The first type of load is, of course, very typical for various control circuits, since it represents, in general, coils of different control devices and what is of particular importance, field windings or rotating machines. The second type of load is typical in the case of a d-c motor drive, where the

rectified and controlled voltage is applied to the armature of a rotating d-c motor. In addition to general formulas the paper analyzes a number of border conditions of special interest and presents two examples of calculations.

45-62-ACO—Principles of Grid Control for Thyratrons; *P. H. Chin (A'41), E. E. Moyer (M'44). 25 cents.* This paper is intended as a preamble to a study of practical circuits for grid control of thyratrons. In addition to a detailed discussion of the basic methods of grid control, it includes the control characteristics of thyratrons with an alternating potential applied to the anode. In this paper, basic methods of grid control are classified into three categories:

1. Control by a direct potential.
2. Control by an alternating potential.
3. Control by a combination of direct and alternating potentials.

One-tube elementary circuits are used to illustrate the basic schemes of grid control, together with diagrams of wave forms to describe the successive stages of control actions.

Industrial Power Applications

45-21—Dodge Chicago Plant's Electric-Power-Distribution Scheme With Airplane-Engine-Testing Power Recovery; *E. L. Bailey (F'43). 15 cents.* The paper gives a brief outline of the electrical distribution of light and power for the project with a tabulation showing connected load, load factors, and estimating of kilowatt demand. Different airplane-engine testing equipments then are described, giving a full account of the slip-ring generator used without a slip-type coupling as the unit selected for this plant. A typical engine test cell is shown in a cutaway drawing, with full description in the text. A circuit diagram shows how 60-cycle power is recovered and measured in the stator, with loading resistors for dissipating the slip losses from the rotor. Finally, observations are made regarding the use of series and shunt capacitors for voltage regulation and power-factor correction, along with general comments on the performance of the system.

45-71—Application of Electric Equipment for Propeller Milling Machine; *H. E. Morton, O. G. Rutemiller (M'41). 15 cents.* The propellers used on large vessels are sometimes as much as 24 feet in diameter. Accurate surface contour is necessary for maximum efficiency and minimum erosion. In the past, the surfaces of such propellers have been finished almost entirely by hand, a time-consuming job that does not lend itself to high accuracy. The recently developed Morton ship-propeller milling machine has provided the Naval designers and shipbuilders with a tool that will generate accurately the contours of both sides of a propeller blade simultaneously at a tremendous saving of time and with the elimination of the greater part of the handwork and its inaccuracies. The application of wide-speed-range adjustable-speed d-c motors, a new and unique electric position regulator, and modern full magnetic control have made this machine possible. The primary feed motion is driven by a Rototrol-regulated wide-speed-range drive, which provides easy and accurate control of the operating speeds over a wide range with good speed regulation as well as accurate control over the rates of acceleration and retardation. The position regulators make it possible for the machine to follow the contours of scale models with such a degree of accuracy that amplifications of as much as five to one are possible, and the resultant deviation from the desired contour is much less than heretofore possible. The magnetic control provides for the safety of the operator, the machine, the cutters, and the work. It makes the machine follow an automatic sequence of operations, when the machine is cutting, and provides finger tip control of all motions to facilitate and speed up a rather tedious setting-up operation. This machine is a very good illustration of the potential possibilities of design, when machine designers and electrical equipment designers co-operate fully in the conception and development of an intricate machine.

45-25—The Design of Bus-Bar Industrial Distribution Systems: an Epitomization of Available Data; *T. J. Higgins (A'40). 30 cents.* This paper is written to acquaint the designer of bus-bar industrial distribution systems with the extent and location of the theoretical and experimental data available for design purposes. Attention is confined to those factors that essentially determine the operating characteristics of a bus-bar distribution system: voltage drop, temperature rise, and short-circuit capacity. Epitomization of the pertinent content of 575 apposite references is presented. A guide is provided to most, possibly all, of the consequential literature on the design of bus-bar distribution systems, including many forgotten or little-known papers containing valuable material not to be found elsewhere. As to the practical usefulness of such a guide, it may be said that the designer who acquaints himself with all of the information detailed in the writings mentioned will be enabled:

1. To better his own design procedures.
2. To improve on present bus designs.
3. To forestall costly experimentation undertaken to obtain data either extant—but unknown to those proposing experiment—or possible of calculation from existing theory.

45-72—Application of Capacitors for Power-Factor Improvement of Induction Motors; *W. C. Bloomquist (A'43), W. K. Boice (M'43). 20 cents.* The practice of connecting capacitors at the motor terminals in order to permit switching the capacitors and motor as a unit will not result in adverse motor operation, if the amount of capacitors is properly selected. A few problems to be considered are:

1. Overvoltage due to self-excitation.
2. Transient torques.
3. Overvoltage in current-transformer secondary circuits.
4. Overload protection for the motor.

This paper discusses these problems and explains the necessity of limiting the amount of capacitors to be connected to a motor, when both are switched as a unit. A useful application table is included, listing the maximum capacitor rating for motors and the reduction in line current with the recommended capacitor rating; this latter information is helpful for selecting the proper motor-overload protective device. Information and data are included showing the relative economics of power-factor improvement by capacitors with individual motors and the group-capacitor method.

45-47—Tracer-Controlled Position Regulator for Propeller Milling Machine; *C. R. Hanna (M'39), W. O. Osbon (M'41), R. A. Hartley (A'43). 20 cents.* The position regulator designed to control the ship-propeller milling machine discussed in a companion paper by Mr. Rutemiller and Mr. Morton is described in detail. The regulator makes possible the machining of large propellers in conformity to scale models with speeds and accuracies heretofore unobtainable. It consists essentially of a variable-voltage drive controlled through an amplifier and exciter by a Silverstat tracer unit designed to accommodate propeller-to-model ratios from 2:1 to 5:1. The various circuit arrangements required to stabilize the regulator and to insure accurate following over a wide range of speeds and accelerations are explained. A typical stability calculation is given in the appendix.

45-79—Modern Electric-Power-Distribution Ideas as Applied in a Large War Plant; *R. H. Kaufmann (M'41), N. A. Kieb (M'43). 25 cents.* This paper describes the design and installation of the electric distribution system incorporated in the Kansas City Pratt and Whitney aircraft engine plant involving over 2,000,000 square feet of working area. Conservation of material and time were of paramount importance. An electric system substantially independent of building structure was sought and attained. Modern economical principles of load-center power distribution are applied, using the secondary selective arrangement for service reliability. Features contributing much to over-all economy include:

1. 460/265-volt service in factory areas serving 440-volt polyphase motors and 265-volt fluorescent lighting units.
2. Spaced single-conductor low-voltage feeders of moderate cross section feeding short lengths of 250-ampere plug-in bus.
3. Overhead cable troughs for 13.8-kv feeder cable.
4. Air-pressure cooling of main incoming service transformers.

For the major part, the economies effected in this installation fundamentally are sound and should prove useful in securing more economical power distribution in future industrial plants.

45-80—Induction Heating of Moving Strip; *R. M. Baker (M'40). 30 cents.* Induction heating at frequencies of several hundred kilocycles per second has been used very successfully to melt the surface and brighten electrolytic tin plate at a strip speed of 1,000 feet per minute. This paper gives a complete analysis of the problems of heating moving magnetic strip, and shows when it is necessary to use radio-frequency power and when the heating may be accomplished satisfactorily at rotating machine frequencies (9,600 cycles per second or less).

Instruments and Measurements

45-19—A Modulated-Frequency System of Telemetering; *H. E. Renfro, A. P. Peterson (A '32). 15 cents.* This paper describes the operation of a modulated-frequency system of telemetering, which was developed as a result of an urgent need of the City of Seattle Department of Lighting for a telemetering system which would provide high-speed continuous visual indications. Other requirements were: that the indications be independent of variations in line characteristics and that several indications be transmitted simultaneously over existing telephone pairs without interruption of communication. Modulated frequency, as the transmitted quantity in telemetering, has been used in the past, and this paper is in no way meant to imply that these other schemes have been unsuccessful. The authors believe, however, that the means described of controlling the frequency at the transmitting point and measuring the frequency at the receiving point is unique.

45-24—Orthomagnetic Bushing Current Transformer for Metering; *A. Boyajian (F '26), G. Camilli (F '43). 15 cents.* If a magnetic core is excited simultaneously at two different frequencies, three interesting phenomena may be observed:

(a). The lower-frequency hysteresis loss may be reduced or even wiped out, while the higher-frequency losses are considerably increased.

(b). Under certain conditions, there may also be observed a reduction in the lower-frequency exciting current and an increase in the higher-frequency exciting current.

(c). If the frequency and the flux density of the higher-frequency excitation are chosen properly and maintained, the lower-frequency volt–ampere excitation curve of the core can be rendered practically a straight line over a wide range of the lower-frequency flux density.

If the lower frequency is the operating frequency of a current transformer, every one of these items is beneficial toward securing greater current-transformer accuracy, item (c) being the most important one because it renders the ratio and phase-angle errors constant and, therefore, precise compensations for them possible. Data are furnished on bushing-current transformers of such design for high voltages and low currents with greatly improved accuracy, using triple-frequency auxiliary excitation. Because of item (c) the authors have christened the core and the device orthomagnetic.

45-64—An Interval Timer for Arc Duration; *J. S. Quill (A '43). 15 cents.* This paper describes a laboratory instrument which was developed for the purpose of measuring the time in milliseconds that an arc exists when an electric circuit is opened. The instrument uses signals obtained from the arc voltage and circuit current, respectively, to start and to stop a timing circuit, consisting of a capacitor charged linearly with time by the constant current of a pentode. Besides the description of the new instrument, the paper describes how it has been used for the investigation of both a-c and d-c arc interruption and for the accumulation of information on problems relating to arc interruption.

45-65—Dynamic Measurements on Electromagnetic Devices; *E. L. Norton. 25 cents.* The paper describes a method for the point-by-point measurement of the instantaneous value of flux, current, displacement, and velocity of electromagnetic apparatus, such as relays. The time during the cycle of operation may be accurately set, and the readings are made from the steady deflection of a d-c instrument. The apparatus is described in detail, and the results of some typical measurements are given.

45-66—A Portable Instrument for Measuring Insulation Resistance at High Voltage; *F. W. Atkinson (M '37), R. B. Taylor. 15 cents.* There has been an increasing trend toward measuring insulation resistance of high-voltage machines and cables at or above their rated voltage by the use of direct current. Up to the present the equipment for this type of testing has been large and heavy. The new portable tester described in this paper will stimulate greatly collection of valuable data on insulation testing and insulation resistance throughout the industry. The new instrument—rugged despite its light weight (31 pounds)—was made possible by the development of a new cold-cathode rectifier tube, which also is described. The tester now is being used in the evaluation of aircraft ignition systems. Some exploratory work has been done with it in the industrial field, where its potentialities appear highly promising. Lightweight power supplies and insulation-resistance testers may be designed for voltages up to 200,000 volts or higher.

Land Transportation

45-10—Electrification and Signaling of the Canadian National Railways' Terminal, Montreal, Canada; *R. G. Gage. 15 cents.* The Montreal Terminal was completed in 1943 to co-ordinate existing passenger and develop additional freight facilities to meet wartime traffic. The electrification is an extension of existing 2,400-volt d-c system and is supplied from eight Hewittic glass-bulb rectifier units, the first installation of the kind for traction purposes in Canada. Train operation throughout 12 miles of terminal main track is by signal indication only and is controlled by two electric relay-type interlockers, situated one on each side of the St. Lawrence River. One of these comprises, perhaps, the largest interlocker of its kind, when the area involved is considered. This is made possible by the use of a new high-speed signal code. This centralization of control has resulted in a large reduction in terminal train delays.

45-11—Grounding of Circuits on Self-Propelled Vehicles; *D. D. Ewing (F '21). 15 cents.* There is a lack of standardization and uniform practice, in connection with the grounding of circuits on self-propelled vehicles, such as locomotives and busses, which in some areas now is affecting development. This paper presents a brief survey of current practice and certain conclusions, all prepared with the idea of bringing out constructive criticism and new viewpoints. It is suggested that the Institute sponsor a committee, representing the interested agencies, to develop the desired standards and recommended practices.

45-17—Mercury-Arc Rectifiers for Railroads; *S. S. Watkins (M '26). 15 cents.* Present status and design trends are examined for their significance in design of d-c power supply for electric traction. Maintenance cost of rectifiers on railroad load is found to be about half that of synchronous converters. Estimated space and cost are presented for substations using present-day rectifiers. Rectifier groups of 36 or more phases have been used in electrochemical industry, but 6-phase and 12-phase rectifiers have been satisfactory in railroad service. Recent mass production has stimulated design improvement of single-anode rectifiers. For 650-volt railroad load new manufacture of multi-anode rectifiers is not expected. For 3,000-volt service both single-anode and multi-anode rectifiers now are obtainable. Sealed steel-tube rectifier substations are suggested for 600-volt trolley-coach systems. Anode circuit breakers have widened the choice of high-speed switching for railroad substations. Grid control and ignitor timing are methods available for limiting rectifier load or for producing compound characteristics.

45-31—Compressed-Air Circuit Breakers in A-C Railway Service; *H. M. Wilcox (M '27), D. C. Harker (A '38). 15 cents.* The increasing interest in compressed air as an interrupting and operating medium for circuit breakers in central-station and industrial service, together with its gratifying record in service periods extending up to five years, warrant investigation of its application to a-c railway service. Previous developments leading up to present standards of requirement for this service are reviewed, and a description is given of a compressed-air circuit breaker designed for high-speed interruption of short circuits on contact-line feeders in single-phase 25-cycle railways service at 12,000 volts to ground. Application of the principle to other railway service is discussed.

Power Generation

45-34—Frequency Changers—Characteristics, Applications, and Economics; *S. B. Crary (M '37), R. M. Easley. 25 cents.* This paper deals with frequency changers for interconnected power systems of different frequencies. The characteristics of synchronous and nonsynchronous ties are discussed followed by a brief description of the essential performance characteristics of five different types of frequency changers. Attention is given particularly to the requirements for the important steel-mill and railroad-electrification applications. Included is an economic discussion which presents relative costs and losses. It is concluded that the synchronous–synchronous type of frequency changer is best suited for supplying power for low-frequency railroad electrification, whereas the induction–synchronous load-regulating and the electronic load-regulating frequency changers best meet the requirements for confining objectionable load changes to the system where they originate.

45-36—Proposed Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Turbogenerators; *AIEE-ASME Joint Committee on Turbogenerators. 20 cents.* Recommendations for preferred ratings of large turbogenerators have been presented in this report. Six ratings are proposed instead of the present 11 ratings.

Steam conditions and electrical rating characteristics are standardized. In addition, the AIEE group has recommended standard specifications for the generators. It is expected that adoption of the proposed standards will reduce costs relative to present-day values and also shorten delivery time. It is expected that standardization of the turbogenerators will not stifle development but should make available more effort for research and improvement.

Power Transmission and Distribution

45-13—Improving Stability by Rapid Closing of Bus-Tie Switches; *E. W. Kimbark (M '35). 15 cents.* Intermediate busses on a double-circuit line are detrimental to stability during the existence of a fault but are beneficial after clearing. Therefore it is proposed to use bus-tie switches which are initially open but which close simultaneously with the opening of the line breakers soon after a fault occurs. Calculations on a particular system, consisting of a hydroelectric station transmitting over a high-voltage double-circuit line to a large receiving system, show that the power limit (based on nine-cycle clearing of a two-wire-to-ground fault at the sending end) is raised 12 per cent by rapid closing of high-voltage bus ties at both ends. This increase is greater than that obtainable through high-speed reclosure and equals the gain obtainable through going to six-cycle clearing. Unlike reclosing, the proposed switching is beneficial with permanent faults or with sequential clearing.

45-18—Lightning Investigation on 132-Kv System of American Gas and Electric Company; *I. W. Gross (M '40), G. D. Lippert (A '38). 15 cents.* The results of a field investigation of lightning effects on parts of an extensive 132-kv transmission system, covering the past five years' records, is presented and discussed. Although the investigation was centered largely near the stations rather than out on the line itself, a few records are included from line towers where lightning currents were measured in tower structures, counterpoises, and ground rods. The magnitude of lightning currents at stations ranged from 2,400 to 11,500 amperes in line conductors; from 1,700 to 10,300 amperes in ground wires; and from 500 to 4,100 amperes in arresters located at stations. The first figure in each case above is the median value observed and the second figure the maximum value. The effectiveness of arresters in holding surge voltages to predetermined values is indicated by the data presented. One feature of the investigation was centered around the determination of rates of surge voltage change at the station entrance and within the station. These records showed that the median value was 220 kv per microsecond, and the maximum value was 810 kv per microsecond for lightning surges. The switching surge voltages at the same location ranged from a median value of 70 kv per microsecond to a maximum of 468 kv per microsecond. The effectiveness of multiple circuits emanating from a station in reducing the severity of lightning at the station itself is discussed, and data are presented thereon. In locations where the soil resistivity is fairly high and the soil a sandy loam, it is found that long ground rods ranging up to 120 feet in length are considerably more effective than buried counterpoises of 250 feet in length. Other comparisons of the effectiveness of counterpoises, ground rods, and tower footings also are presented and discussed.

45-26—Lightning Investigation on Transmission Lines—VIII; *W. W. Lewis (F '38), C. M. Foust (M '37). 30 cents.* Previous papers of this series gave data on a lightning investigation carried on co-operatively by a number of power companies and the General Electric Company, and the seventh paper of the series brought the data up to and including 1938. Additional papers covered special angles of the investigation. The present paper discusses an investigation under the joint sponsorship of the American Gas and Electric Service Corporation of voltages, currents, and rates of change of voltage at five stations of the Appalachian Electric Power Company in Virginia; information on currents in towers and strokes on the lines of five different power companies; and some additional data on the distribution of current in counterpoise wires and driven rods, and voltage gradient near towers on the Consumers Power Company system in Michigan.

45-60—Galvanic Corrosiveness of Soil Waters; *H. S. Phelps (A '21), Frank Kahn (A '36). 15 cents.* Results are presented of a study of relation of *pH* of soil waters to galvanic action between couples of lead, copper, iron, and carbon. Galvanic cell tests were made using as electrolytes actual soil waters or soil extracts from 31 locations at which trouble had been experienced. The following conclusions apparently can be drawn:

1. Galvanic corrosiveness on lead, copper and iron appears generally more severe for soil waters of low *pH* than for those of high *pH*.

2. Indications are that static potentials of lead and iron are practically constant in soil electrolytes of *pH* up to approximately ten. As *pH* is increased above ten, lead becomes more negative and iron more positive. The potential of copper becomes more negative in substantially straight-line relation with increasing *pH*.

3. For electrodes of lead, copper, iron, and carbon in soil waters, a relation between degree of polarization and *pH* of electrolyte is indicated.

45-58—The Dielectric Strength and Life of Impregnated Paper—IV; *J. B. Whitehead (F '12), J. M. Kopper (M '43). 25 cents.* High-stress short-time tests of cable-type impregnated-paper insulation show that a higher-density paper has a lower breakdown strength. The results confirm those of earlier tests in which a step-voltage test over longer times was used. The behavior is much the same for both a light and a heavy oil. A method is described for detecting the first occurrence of gaseous ionization in impregnated-paper insulation and for taking a continuous record of its growth up to breakdown. Interruptions of the tests at various stages as revealed by the ionization recorder show that ionization and failure almost invariably begin in the oil channels and that a time element enters in both preionization and subsequent ionization periods. The mechanism of breakdown, power factor, and capacitance variation as related to paper density are discussed and explained in terms of fundamental conductance phenomena in insulating oils.

45-59—Electrolysis and Corrosion of Underground Power-System Cables; *L. J. Gorman (M '30). 25 cents.* The paper presents a summary of the principles and methods used for the mitigation of electrolysis and corrosion on the underground-cable system of the Consolidated Edison Company of New York, Inc. The test procedures used for stray-current electrolysis are not suitable for the electrolytic types of corrosion. A duct survey has been developed which replaced the manhole tests formerly used for stray-current electrolysis investigations. The procedure for making the duct survey is described. The methods used for the analysis of duct survey data are presented together with the results obtained on the system over a period of approximately four years. The classification of corrosion used by the Consolidated Edison Company is presented together with its application to the corrosion failures experienced on the cable system over a four-year period. The measures used for the mitigation of cable-sheath corrosion are discussed briefly, including electrolysis drainage, cathodic protection, protective covering, cable grease protection, and use of zinc for cathodic protection.

45-61—Study of A-C Sheath Currents and Their Effect on Lead-Cable Sheath Corrosion; *C. M. Shrrer (A '39), K. J. Granbois (A '31). 15 cents.* Destruction of lead sheaths on underground cables by corrosion usually can be attributed to stray direct currents, the proximity of dissimilar metals, or direct potentials resulting from unfavorable soil or duct conditions. Alternating current generally has been considered a relatively unimportant factor in corrosion. This paper discusses two cases of insulation failures on single-conductor power cables resulting from sheath corrosion and describes field observations and laboratory tests which indicate that the corrosive action was accelerated greatly at first by rectified alternating currents induced in the sheaths by the load current. Experiments show that lead, when placed with copper in water removed from cable ducts, rectifies alternating current. The rectified current initially is in the direction to make lead anodic and produces corrosion; later a reversal of polarity takes place and lead becomes cathodic. A method of controlling such corrosion is described.

45-67—Impedances Seen by Relays During Power Swings With and Without Faults; *Edith Clarke (M '33). 30 cents.* The paper reviews briefly the work previously done in determining the performance of distance relays during power swings by means of impedance charts and extends this work to include any three-phase system which can be replaced during power swings by two equivalent synchronous machines with balanced generated voltages connected by a symmetrical three-phase linear network in which positive- and negative-sequence impedance can be assumed equal. Power swings during all types of unsymmetrical faults, as well as during symmetrical system conditions, are considered. For the convenience of the busy engineer, the paper is divided into three parts. The development of the method of constructing system impedance charts from equations in specified form in part II and the derivation of these equations in part III are necessarily complex; but the

actual construction of an impedance chart, explained and illustrated in part I, requires very little effort. By the adaptation of a general impedance chart, the behavior of distance relays on a given system can be quickly determined, and, more important, relays having characteristics best suited to a specific application can be selected.

45-77—The Combination of Supervisory Control With Other Functions on Power-Line Carrier Channels; *R. C. Cheek* (*A'42*), *W. A. Derr* (*A'43*). *15 cents.* The use of a single-carrier channel to perform several different functions is becoming increasingly common. This practice is encouraged by considerations of economy of equipment and conservation of space in the carrier-frequency spectrum. The requirements of carrier-relaying, telemetering, communication, and load-control systems are generally well understood, and the combination of two or more of these functions on a single-carrier channel is relatively straightforward. However, the channel requirements of supervisory-control systems are not so well known, and the combination of supervisory control with one or more other functions on a carrier channel requires an understanding of the limitations involved. In this paper the carrier-channel requirements of a standard supervisory-control system are discussed, and methods of combining supervisory control with one or more other functions are given. These methods include both the single-station and the multistation types of supervisory control.

45-78—Power-Line Carrier Channels; *M. J. Brown* (*A'37*). *20 cents.* The attenuation of high-frequency currents in power-line carrier channels is discussed from the theoretical viewpoint, and the experience with losses actually encountered is compared with theoretical conclusions. The operating conditions where coupling-capacitor losses are important are outlined. Curves indicating losses through carrier-current line traps are presented.

Protective Devices

45-37—Temperature Limits and Abstracts of Present Standards and Practices for Stationary-Contact Surfaces; *AIEE subcommittee on conduction in stationary contact surfaces. 15 cents.* This paper covers a survey of the present standards of the AIEE, National Electrical Manufacturers Association and Underwriters' Laboratories on the permissible temperature rises of various types of stationary-contact assemblies. A table comparing these limits is given together with abstracts of the Standards dealing with contact temperatures. Wartime standards are mentioned but are not included in the table or in abstract form.

45-43—Field Tests and Performance on Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air-Blast; *Philip Sporn* (*F'30*), *H. P. St. Clair* (*F'44*). *30 cents.* The heavy expansion brought about on the Central system of the American Gas and Electric Company in response to demands for power during the defense and war periods has produced a requirement for circuit-breaker rupturing duties close to 3,500 megavolt-amperes. In order to test the interrupting performance and reliability of two types of 138-kv 3,500-megavolt-amperes circuit breakers—the first an oil, the second an air-blast design—and also to explore faster reclosing cycles than now are offered by the most improved oil circuit breakers, high-capacity field tests were carried out at the Philo plant of the Ohio Power Company. In these tests, involving 20 interruptions on each breaker, successful interruption of a full three-phase short circuit of 3,500 megavolt-amperes with three-cycle interruption and with 13-cycle reclosure has been accomplished for the first time. The results of these tests, it is believed, indicate that a goal of 5,000 megavolt-amperes with 12-cycle reclosure is definitely attainable.

45-44—A Three-Cycle 3,500-Megavolt-Ampere Air-Blast Circuit Breaker for 138,000-Volt Service; *H. L. Byrd* (*A'43*), *B. S. Beall, III* (*A'41*). *15 cents.* The latest development in outdoor air-blast circuit breakers has been a three-cycle, 138-kv air-blast circuit breaker having an interrupting rating of 3,500 megavolt-amperes. This breaker has undergone extensive laboratory test and was proved entirely satisfactory in its ability both to handle the high currents which correspond to the megavolt-ampere interrupting rating and to have a comfortable margin on its interrupting time of three cycles. Because of the desire for high-speed reclosing, this breaker was set up to have a reclosing time of approximately 14 cycles, and it has operated successfully under this severe duty. At the completion of laboratory tests, this breaker was submitted for field tests under actual operating conditions and performed with entire satisfaction under all conditions up to 3,500,000 kva. Ultrahigh-speed reclosing operations also were made under actual field conditions up to 3,500,000 kva, the highest power concentrated to date in such tests. This paper describes the theory of operation, the construction, and some of the interesting data which were obtained during development and test of this air-blast circuit breaker.

45-45—A High-Capacity High-Voltage Three-Cycle Oil Circuit Breaker; *H. L. Byrd* (*A'43*), *E. B. Rietz* (*A'42*). *15 cents.* This paper describes the development of a high-voltage high-speed oil circuit breaker to meet three-cycle performance up to 3,500,000 kva at 138 kv. The important design features of the interrupting contacts and operating mechanism are reviewed. There is a description of the laboratory testing methods used to predict accurately the performance which was subsequently demonstrated during the highest-capacity field tests on record.

45-46—The Next Step in Interrupting Capacity—5,000,000 Kva; *A. W. Hill* (*M'41*), *W. M. Leeds* (*M'38*). *20 cents.* Serious consideration is being given to large power-system interconnections which could develop short circuits at certain locations in excess of 3,500,000 kva. High-voltage oil-circuit-breaker capabilities for such heavy duty are reviewed in this paper, the fundamental design requirements outlined, and results of high-power laboratory tests presented which demonstrate that interrupting capacity ratings as high as 5,000,000 kva are feasible. Laboratory test methods for demonstrating these extremely high arc-rupturing ratings are evaluated. The importance of verifying high-speed reclosing performance with high-power tests is emphasized, and on the basis of data already obtained standard reclosing-time intervals considerably less than 20 cycles are foreseen.

45-52—Anode-Circuit-Breaker Design and Performance Criteria; *E. W. Boehne* (*F'43*). *25 cents.* At the time of arc-back in a mercury-arc rectifier, following the conducting period, an effective asymmetrical alternating voltage generates a unidirectional current which is void of natural current zeros. The first duty of the anode breaker is to develop a counter current which neutralizes this arc-back current, thus creating a current zero. This can be accomplished only by developing sufficient arc voltage in the anode breaker. The effect of the shape of the arc-voltage characteristic of the anode breaker and its time of introduction into the circuit are described on a quantitative basis which reveals the relative magnitude of the peak arc current, arc energy, and the location of the current zero with respect to inverse voltage of the rectifier. Several new and interesting features are revealed. The effect of rectifier drop and circuit resistance are included in the analysis. The essential design features of the *AG-2* high-speed anode circuit breaker are presented together with oscillographic verification of its performance on large industrial circuits having rates of rise of current in excess of 10,000,000 amperes per second.

45-54—Improved Fault Protection for Rural Distribution Systems; *A. Van Ryan* (*A'44*). *15 cents.* This paper describes an improved oil circuit recloser which has been designed to reduce the number of outages on rural distribution systems. Automatic oil circuit reclosers now in use are limited in application because of their inability to coordinate properly with fuse links on the load side of the recloser. This new automatic oil circuit recloser incorporates the advantages of fast opening on the first and second operations to clear all transient faults on the protected section and of operating with time delay on the third and fourth operations to permit the sectionalizing fuse to blow, and thus it isolates a permanent fault without causing a lockout of the recloser.

45-55—Rectifier Relay for Transformer Protection; *E. L. Michelson* (*M'44*). *15 cents.* In differential protection of transformers, the effect of inrush currents plays an important part. This current is equivalent to fault current and tends to operate a differential relay. This paper describes various methods that have been used to eliminate the effect of inrush currents and particularly describes a new relay for this purpose. The new relay uses dry-type rectifiers and separates the differential current into its positive and negative components. In the case of inrush currents, the current is predominately of one polarity, and the relay will not trip. Under fault conditions, currents of both polarities appear and cause tripping of the relay. The paper describes the construction of the relay, laboratory tests, and an actual installation.

45-56—New Solenoid Mechanism for Magne-Blast Breakers; *B. W. Wyman (A '40), J. H. Keagy (A '42). 25 cents.* When a circuit breaker is closed in upon a short circuit, the closing motion is retarded by high magnetic forces at the time the fault current is initiated. These retarding forces increase as the square of the fault current. If the fault current be sufficiently high, these forces may stall completely or, even more seriously, slowly reverse the closing motion. The result is severe arcing and disturbance within the breaker, until it is tripped. In some mechanisms this condition often is aggravated by subnormal control voltage at the coil terminals, which further reduces the ability of the mechanism to close the breaker. This paper describes a solenoid mechanism design used for operating the Magne-blast circuit breaker, which is effective in closing the breaker against short-circuit currents as high as 80,000 amperes without damage to the breaker contacts. The departure from the conventional magnetic circuits of the solenoid responsible for this superior closing performance also minimizes the effect of subnormal control voltage.

45-57—Nine Years Experience With Ultra-high-Speed Reclosing of High-Voltage Transmission Lines; *Philip Sporn (F '30) C. A. Muller (M '36). 15 cents.* Data covering nine years' operating experience with 91 ultrahigh-speed-reclosing circuit breaker installations mainly on a large interconnected and integrated high-voltage system are presented and analyzed: out of 635 cases of flashover cited, 570 reclosures were successful and 65 cases of reclosure were unsuccessful, a record of 89.8 per cent successful reclosure. Double-circuit lines show a record of unsuccessful reclosure double the average, but 80 per cent of the apparently unsuccessful reclosures resulted in successful reclosure of one circuit. The conclusions drawn are that ultrarapid reclosure has proved itself a tool of major importance for use in improving high-voltage-line reliability; that its use can, and should be, extended to lower-voltage lines; and that further improvements are in sight as a result of recent improvements in circuit-breaker opening and reclosure time.

PERSONAL

E. F. W. Alexanderson (A '04, M '13, F '20) consulting engineer, General Electric Company, Schenectady, N. Y., has been awarded the Edison Medal for 1944 "for his outstanding inventions and developments in the radio, transportation, marine, and power fields." Doctor Alexanderson, the 34th recipient of the medal, was born on January 25, 1878, in Upsala, Sweden. He was graduated from the Royal Institute of Technology, Stockholm, in 1900 and has been awarded honorary degrees by Union College (1926) and by the Royal University of Upsala (1938). Doctor Alexanderson came to the United States in 1901, entered the General Electric Company in 1902 as draft man, and in 1904 transferred to the engineering department. From 1919 to 1924 he was also chief engineer of the Radio Corporation of America

W. R. Wilson

for whom he superintended the construction of powerful radio stations in Sweden, Poland, England, Hawaii, California, and on Long Island. He was a pioneer in television and the first home reception of television took place in his home in 1927. His other contributions to radio include the Alexanderson high-frequency alternator, multiple-tuned antenna, vacuum-tube radiotelephone transmitter, and tuned-radio-frequency receiver, and, in addition, he holds many patents in the power and control fields. Doctor Alexanderson is a past president of the Institute of Radio Engineers and a member of the Royal Academy of Science, Sweden. Among other honors he has received the Order of the North Star, Sweden; the Order of Polonia Restituta, Poland; the Gold Medal of the Institute of Radio Engineers; and the John Ericsson Medal.

C. L. Collens (A '07, M '40) president of the Reliance Electric and Engineering Company, Cleveland, Ohio, has been elected to the newly created post of chairman of the board. Mr. Collens is a graduate of Yale University (1896) and Columbia University (1897). In 1897 he joined the staff of the Hartford Electric Light Company, Hartford, Conn.; in 1899 he was with the International Acheson Graphite Company, Niagara Falls, N. Y.; and in 1906 with the Niagara Power Company, Niagara Falls. Mr. Collens has been president of the Reliance Electric and Engineering Company since 1907. **A. M. MacCutcheon** (A '12, F '26) engineering vice-president, has been elected senior vice-president. Mr. MacCutcheon was graduated from Columbia University in 1908. He joined the Reliance Electric and Engineering Company in 1914 and was made engineering vice-president in 1923. He is a past president of AIEE.

W. R. Wilson (A '43) General Electric Company, Pittsfield, Mass., has been awarded the Alfred Noble Prize for 1944 for his paper, "Corona in Aircraft Electric Systems as a Function of Altitude" (AIEE *Transactions*, volume 63, 1944, April section, pages 189–94). Mr. Wilson was born on May 3, 1919, in South Bend, Ind. In 1941 he was graduated from the University of Michigan with the degree of bachelor of science in engineering physics. Following his graduation, Mr. Wilson became an assistant in the research laboratory of the General Electric Company, Schenectady, N. Y. In 1942 he transferred to the Pittsfield, Mass., works of the General

E. F. W. Alexanderson

Electric Company as an engineer's assistant. The Alfred Noble Prize was instituted in 1929, and the selection of Mr. Wilson as 1944 recipient brings the award to AIEE for the seventh time.

R. R. Robertson (M '25) chief electrical engineer and deputy general manager, Los Angeles (Calif.) Department of Water and Power, has retired. Mr. Robertson, a graduate of Purdue University (1907) began his career in 1907 as a mechanical draftsman for the Isthmian Canal Commission, Panama. He was employed by them until 1912 when he entered the employ of the Los Angeles Bureau of Power and Light. After service in the United States Army during the first World War, Mr. Robertson returned to the Bureau of Power and Light as construction superintendent. By 1940 he had become head of the division and when the water and power bureaus were merged in November 1943 he became chief electrical engineer and deputy general manager of the Department of Water and Power.

J. E. Hobson (A '36, M '41) director of the school of engineering, Illinois Institute of Technology, Chicago, has been appointed director of the Armour Research Foundation. Doctor Hobson was graduated from Purdue University in 1932 with a bachelor-of-science degree, received his master's degree in 1933, and his doctor-of-philosophy degree from the California Institute of Technology in 1935. In 1936 he taught in the electrical-engineering department of the Illinois Institute of Technology, leaving in 1937 to work for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He returned to the Illinois Institute of Technology as head of the electrical-engineering department in 1941.

Victor Siegfried (A '32, M '38) assistant professor of electrical engineering, Worcester (Mass.) Polytechnic Institute, has been appointed chief research engineer, electric cable works, the American Steel and Wire Company, Worcester. Mr. Siegfried was graduated from Stanford University in 1930 with a bachelor-of-arts degree, and in 1932 he received a degree in electrical engineering. In 1933 he became an instructor in electrical engineering at the Worcester Polytechnic Institute, and in 1937 Mr. Siegfried was appointed assistant professor.

Wallace Montgomery (A '25, M '28) formerly production manager, the G. Washington Coffee Company, Morris Plains, N. J., has been elected vice-president in charge of production. A graduate of Tulane University in 1913, Mr. Montgomery's first position was with the American Beet Sugar Company, Oxnard, Calif. From 1913 through 1926 he held engineering and managerial positions in Mexico and Cuba and subsequently established his own business as consulting engineer in San Diego, Calif. Mr. Montgomery joined the G. Washington Coffee Company in 1927.

Thomas Ingledow (M '41) chief engineer, British Columbia Electric Railway Company, Ltd., Vancouver, British Columbia, Canada, has been made vice-president and chief engineer of the electrical department. Mr. Ingledow was graduated from Glasgow University, Scotland, in 1922 and attended the Royal College of Science in London until 1923. In 1925 he became a design engineer for Montreal (Quebec) Light, Heat and Power Consolidated and in 1940 he joined the British Columbia Electric Railway Company.

J. W. Milnor (A '13, F '30) consulting engineer, Wes ern Union Telegraph Company, New York, N. Y., retired on October 1, 1944. Mr. Milnor was graduated from Lehigh University in 1912. Following his graduation he became an assistant in the laboratory, General Electric Company, Pittsfield, Mass. He entered the employ of Western Union Company in 1913 as engineering assistant, becoming research engineer in 1919, transmission engineer in 1936, and consulting engineer in 1943.

W. M. Gifford (A '18) general sales manager, Aluminum Company of Canada, Toronto, Ontario, retired on September 28, 1944, to assume special duties in connection with the president's office. Mr. Gifford has been with the Aluminum Company of Canada since 1927. Previously he had been employed by the Northern Aluminum Company, Ltd., Toronto, which he joined in 1910 as salesman. His retirement comes on the anniversary of his 40th year in the aluminum industry.

H. R. Searing (A '20, F '30) vice-president, Consolidated Edison Company, New York, N. Y., has been elected a trustee and a member of the executive committee of that company. He has also been elected a director of the New York and Queens Electric Light and Power Company, the Westchester Lighting Company, and the New York Steam Corporation, all of New York.

Lee de Forest (A '04, F '18) director of research, Lee de Forest Laboratories, Los Angeles, Calif., has been active in the organization of a center for electronic research, a factory for the production of radio and television equipment, and a commercial radio station, all in Mexico, Federal District, Mexico.

F. R. Innes (A '25, M '26) managing editor, *Electrical World*, New York, N. Y., has been made associate editor to take charge of expanded treatment of public utilities. He joined the staff in 1925, was made western editor at Chicago, Ill., in 1926, and was appointed managing editor in 1939.

C. F. Kettering (A '04, F '14) vice-president in charge of research, General Motors Corporation, Dayton, Ohio, has been made a member of the subcommittee on applied cyclotronics of the postwar program committee of the State of Ohio.

W. E. Mitchell (A '06, F '22) vice-president and general manager, Georgia Power Company, Atlanta, has been appointed by the United States Chamber of Commerce to its Natural Resources Department committee for 1944–45.

Robin Beach (A '15, F '35) professor and head of the department of electrical engineering, Polytechnic Institute of Brooklyn, N. Y., has organized the firm of Robin Beach Engineers Associated, consulting engineers, Brooklyn.

A. C. Streamer (A '19, M '41) vice-president Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been elected president of the National Electrical Manufacturers Association.

J. B. Clapp (A '24, M '36) sales engineer, James P. Kearny Corporation, New York, N. Y., has joined the Thomas and Betts Company, Elizabeth, N. J., as their special representative in the utility field.

R. P. M. Carmody (A '24) manufacturers' representative, Buffalo, N. Y., has been appointed sales representative in the Buffalo area for the storage battery division of the Philco Corporation.

M. S. Coover (A '16, F '42) professor and head of the department of electrical engineering of the Iowa State College, Ames, has been elected president of the Iowa Engineering Society for 1944–45.

F. R. Lack (M '37) vice-president and manager of the radio division of the Western Electric Company, New York, N. Y., has been elected a director of the Radio Manufacturers Association.

George Hamburger III (A '44) formerly application engineer for the Delta Star Electric Company, Chicago, Ill., will be in charge of the new office of the Copperweld Steel Company, St. Louis, Mo.

Ernst Weber (A '31, F '34) research professor of electrical engineering, Polytechnic Institute of Brooklyn, N. Y., has been elected second vice-president of the New York Electrical Society.

J. E. Sheehan (M '28, F '33) formerly sales engineer, Line Material Company, South Milwaukee, Wis., has been appointed manager of the transformer sales department, Zanesville, Ohio.

W. L. Abbott (A '01, F '13) retired chief operating engineer of the Commonwealth Edison Company, Chicago, Ill., has been made an honorary member of the Chicago Engineers Club.

A. J. Cooper (A '24) assistant manager of the New York district, Allis-Chalmers Manufacturing Company, has been elected president of the Montclair (N. J.) Society of Engineers.

P. R. Plant (A '26) now serving with the United States Naval Reserve at the Naval Boiler and Turbine Laboratory, Philadelphia (Pa.) Navy Yard, has been promoted to the rank of lieutenant commander.

C. E. Tarwater (A '40) operating engineer of the Knoxville (Tenn.) Electric Power and Water Board, will become, in addition to his other duties, acting superintendent of the Board.

L. V. Sutton (A '11, M '38) president of the Carolina Power and Light Company, Raleigh, N. C., has been awarded the honorary degree of doctor of engineering by North Carolina State College.

C. M. Mackey (A '34, M '36) formerly branch manager, Westinghouse Electric Supply Company, Houston, Texas, has been transferred to Dallas as Southwestern district manager.

E. E. Kinney (A '27, M '41) formerly associate professor of electrical engineering, Michigan State College, East Lansing, has been named superintendent of buildings and utilities.

F. E. Bell (M '35) formerly chief engineer, office of war utilities, War Production Board, Washington, D. C., has joined the Maxon Construction Company, Inc., Dayton, Ohio.

F. H. Searight (A '38) acting district manager, the Allis-Chalmers Manufacturing Company, San Francisco, Calif., has been appointed district manager.

David Sussin (A '33) chief engineer, the Kelley-Koett Manufacturing Company, Covington, Ky., has been appointed chief of research.

W. C. Fowler (A '30, M '36) sales engineer, Sangamo Electric Company of Springfield, Ill., at Fort Worth, Tex., has been elected president of the Fort Worth Electronics Club.

A. W. Howell (A '36) engineer, operating division, Union Electric Company, St. Louis, Mo., has been named power supervisor.

T. W. Hill (A '39) now with the British War Office in New York, N. Y., will return to Canada and his editorial post with *Electrical News and Engineering*, Toronto, Ontario.

H. L. Olesen (M '27) assistant sales manager, Weston Electrical Instrument Corporation, Newark, N. J., has been promoted to the position of sales promotion manager.

F. E. Anderson (A '31) major, United States Army Engineers, Sacramento, Calif., has been promoted to the rank of lieutenant colonel.

A. W. Howell (A '36) engineer in the operating division, Union Electric Company of Missouri, St. Louis, has been named power supervisor of that company.

Rolf Selquist (A '25) electrical engineer, Copperweld Steel Corporation, Glassport, Pa., has been appointed consulting engineer.

OBITUARY

Charles Felton Scott (A '92, F '25, HM '29) professor of electrical engineering emeritus, Yale University, New Haven, Conn., and past president of AIEE, died December 17, 1944. Doctor Scott was born on September 19, 1864, in Athens County, Ohio. He was graduated from Ohio State University in 1885 with the degree of bachelor of arts and for a year and a half took postgraduate courses at Johns Hopkins University. Doctor Scott began his electrical career as a wireman for the Baldwin Locomotive Works. In 1888 he entered the employ of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as night assistant in the testing room. In 1891 he became assistant electrician, in 1897 chief electrician, and in 1904 consulting engineer. In the Westinghouse laboratories Doctor Scott assisted Nikola Tesla in the development of the polyphase induction motor. He was with the Westinghouse Company until 1911 when he accepted the professorship of electrical engineering at the Sheffield Scientific School, Yale University. He retired from active professorial duties in 1933. Doctor Scott distinguished himself in the field of engineering as well as that of education. He was the inventor (1894) of the Scott "T" connection by which static transformers are arranged to change two-phase alternating current to three-phase and vice versa. Under his administration as AIEE president (1902–3) Section growth was stimulated, the high-voltage transmission committee was founded, and Student Branches were established. As president, Doctor Scott advocated that the plans for a building for the Institute be extended to include other engineering societies and he was instrumental in interesting Andrew Carnegie who subsequently donated $1,500,000 for the building. In 1902 Doctor Scott was president of the Engineers' Society of Western Pennsylvania and in 1904, at the International Electrical Congress at St. Louis, Mo., he was chairman of the power-transmission section. During 1921–23 he was president of the Society for the Promotion of Engineering Education. In 1935 Doctor Scott was elected chairman of the Engineers Council for Professional Development and in 1936 an honorary member of the Connecticut Society of Civil Engineers. He was vice-president of the National Council of State Boards of Engineering Examiners in 1937 and president in 1938. He was a charter member of the United Engineering Society and also a member of the American Society of Mechanical Engineers and the Illuminating Engineering Society. Doctor Scott was the AIEE Edison Medalist for 1929, and in 1930 he was the recipient of the Lamme Medal awarded by the Society for the Promotion of Engineering Education. During the course of his career, he also received many honorary degrees including the degree of master of arts, Yale University; doctor of science, University of Pittsburgh; and doctor of engineering, Stevens Institute of Technology. On the occasion of Doctor Scott's 75th birthday, September 19, 1939, a testimonial dinner sponsored by the AIEE Connecticut Section was held in New Haven which was attended by representatives of national and local organizations. During 1939 and 1940, many AIEE Student Branches held "Scott diamond jubilee" programs in recognition of Doctor Scott's attainments and special position as founder of the Student Branch. A more comprehensive biography of Doctor Scott appeared in the September 1940 issue of *Electrical Engineering*, pages 349–53.

Francis A. Hubbard (M '23) development engineer, Bell Telephone Laboratories, New York N. Y., died Nov. 6, 1944. Mr. Hubbard was born on April 1, 1890, in Cambridge, Mass., and in 1911 was graduated from Harvard University with a bachelor-of-science degree. He received his degree of master of electrical engineering in 1914. In 1915 he entered the engineering department of the Western Electric Company, New York, N. Y., and, when the company's foreign business was sold to the International Telephone and Telegraph Company, Mr. Hubbard joined its subsidiary, the International Standard Electric Company. As transmission engineer he laid out the Stockholm–Goteborg telephone cable (1920) and the cable connecting Milan, Turin, and Genoa (1922). He returned to the United States in 1930 as transmission engineer for the American Telephone and Telegraph Company and in 1934 transferred to Bell Laboratories as switching research engineer.

H. Linton Reber (A '03, F '13) consulting engineer, St. Louis, Mo., died November 1, 1944. Mr. Reber was born in St. Louis on August 18, 1870, and was graduated from Washington University in 1893 as a civil engineer. His first position was as draftsman for the St. Louis Water Works in 1893. From 1899 to 1922, following sundry engineering jobs, he was chief engineer, general manager, and president of the several telephone companies comprising the Kinloch Telephone system, St. Louis. Also, at times, he was engaged in consultation, designing, and construction of other engineering work. Mr. Reber had been a consulting engineer in St. Louis since 1924. He was a life member of AIEE and a member of the St. Louis Institute of Consulting Engineers, the Engineer's Club of St. Louis, the American Society of Civil Engineers, and the Academy of Science of St. Louis.

Sven R. Bergman (A '04) consulting engineer, River Works, General Electric Company, Lynn, Mass., died November 25, 1944. Mr. Bergman was born on May 23, 1877, in Stockholm, Sweden, and was a graduate of the Royal Institute of Technology, Stockholm. He came to the United States in 1902 and in the same year obtained a position with the General Electric Company in the testing department. During Mr. Bergman's 42 years with the company he worked with both Charles Steinmetz and Elihu Thomson. Since the outbreak of the war he had been specializing in generating equipment for aircraft. Mr. Bergman held many patents on electric machinery. He was the recipient of the Silver Medal at the Panama Pacific International Exposition, San Francisco, Calif., in 1915 and the "Certificate of Merit of the Charles A. Coffin Foundation" in 1934.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on November 21, 1944, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dyer, G. A., outside plant engr., Southwestern Bell Tel. Co., Dallas, Texas.
Musgrove, A. M., Lt. Col., Corps of Engineers, U. S. Army, Camp Shanks, N. Y.
Nethercut, D. W., elec. engr., The Ohio Public Service Co., Elyria, Ohio.
Page, G. I., chief operating engr., Public Service Co. of Oklahoma, Lawton, Okla.
Riggs, A. F., district engr., General Elec. Co., Chicago, Ill.
Robertson, E. B., president, Plastics Mfg. Co., Dallas, Texas.
Seeley, W. J., prof. and dean, Dept. of E.E., Duke University, Durham, N. C.

7 to grade of Fellow

To Grade of Member

Askey, R. O., senior engr., Public Service Co. of Northern Illinois, Chicago, Ill.
Biship, C. F., engr., Philadelphia Elec. Co., Philadelphia, Pa.
Bradley, H. L., president, Allen-Bradley Co., Milwaukee, Wis.
Burton, G. D., associate elec. engr., Navy Dept., Bureau of Ordnance, Washington, D. C.
Deederly, J. E., transmission and protection engr., Michigan Bell Tel. Co., Grand Rapids, Mich.
Eschholz, O. H., mgr., Patent Dept., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Fountain, L. L., elec. engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Francis, J. S., elec. distribution engr., Consumers Power Co., Jackson, Mich.
Freeman, Stephen, engr., Consumers Power Co., Jackson, Mich.
Graybill, H. W., design engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Hill, C. G., partner, J. G. Wray & Co., Chicago, Ill.
Hoover, D. B., elec. design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Hornbecker, G. A., elec. supt., Chase Metal Works, Waterbury, Conn.
Hunt, O. D., engr., Sylvania Electric Products, Inc., Salem, Mass.
Joeberger, F. G., supervising distribution engr., Long Island Lighting Co., Mineola, N. Y.
Kisch, J. P., standards and appliance engr., Public Service Electric & Gas Co., Maplewood, N. J.
Koiner, J. S., supt. of elec. installations, General Electric Co., Philadelphia, Pa.
Linde, L. J., engr., General Elec. Co., Philadelphia, Pa.
Lotze, A. W., Lieut. USNR, Anacostia Station, Washington, D. C.
Mallory, D. D., staff member, Mass. Inst. of Technology, Cambridge, Mass.
McIntyre, M. V., chief elec. engr., U. S. Engineer Office, Santa Fe, N. Mex.
Myers, E. H., elec. design engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Nugent, H. M., elec. engr., Otis Elevator Co., New York.
Prince, M. A., asst. design engr., General Electric Co., W. Lynn, Mass.
Risler, C. B., industry engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Scheffer, S. L., relay engr., Long Island Lighting Co., Roslyn, N. Y.
Smith, J. A., mgr., Australian General Elec. Pty. Ltd., Hobart, Tasmania, Australia.
Spencer, N. C., elec. engr., Gulf States Utilities Co., Beaumont, Texas.
Sperow, L. H., engr., General Electric Co., Philadelphia, Pa.
Spitler, C. H., elec. design engr., Leland Elec. Co., Dayton, Ohio.
Staff, V. E., chief of staff, DeLeuw, Cather & Co., Chicago, Ill.
von Roeschlaub, F., design engr., General Elec. Co., Philadelphia, Pa.
Wilder, R. D., engr., Public Service Elec. & Gas Co., Trenton, N. J.
Wotherspoon, H. H., service engr., M. Klein & Sons, Chicago, Ill.

34 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before January 31, 1945, or March 31, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Member

Albert, N. M. (Reelection), Pac. Gas & Elec. Co., Emeryville, Calif.
Allen, A. J., Univ. of Pitt., Pittsburgh, Pa.
Bell C. C., United Shoe Mach. Corp., Beverly, Mass.

Burns, J. H. (Reelection), Rural Elec. Adm., St. Louis, Mo.
Candler, G. L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Cooley, M. C., W. N. Matthews Corp., St. Louis, Mo.
Coyle, C. F., Memphis St. Ry. Co., Memphis, Tenn.
Crawford, A. E., R. F. Equipment, Ltd., Amersham, England
del Valle, A. F. A., P. R. Water Res. Auth., San Juan, P. R.
Doocy, E. B., Stone & Webster Engg. Corp., Knoxville, Tenn.
Drazen, Y., Michael Drazen & Associates, St. Louis, Mo.
Eyton, J. (Reelection), Ste. Anne Paper Co., Ltd., Beaupre, Que., Can.
Fortescue, S., Tenn. Valley Auth., Knoxville, Tenn.
Gibble, S. L., Amer. Tel. & Tel. Co., Philadelphia, Pa.
Glover, R. F., Cons. Engr., Oak Park, Ill.
Hall, F. S., Great Amer. Ind., Meriden, Conn.
Harvey, O. M., Laclede Steel Co., Alton, Ill.
Honnell, M. A., Ga. School of Tech., Atlanta, Ga.
Jenks, H. C. (Reelection), Westinghouse Elec. & Mfg. Co., Cincinnati, Ohio
Jordan, R. C., Ohio State Univ., Columbus, Ohio
Kaldor, E., Plastic & Diecasting, Ltd., Christchurch, N. Z.
Keeling, H. J., Southern Counties Gas Co. of Calif., Los Angeles, Calif.
Klein, J. E. (Reelection), Canadian Laco Lamps, Ltd., Montreal, Que., Can.
Kuhn, H. H. (Reelection), Kansas City Pr. & Lt. Co., Kansas City, Mo.
Kuhner, S. W. (Reelection), Marion-Reserve Pr. Co., Marion, Ohio
Leland, G. F., Gen. Elec. Co., Schenectady, N. Y.
McClean, H. G., Crompton Parkinson, Ltd., Chelmsford, England
Mehta, I. M., Kaycee Ind., Ltd., Shikohabad, U. P., India
Miller, E. A., Giffels & Vallet, Detroit, Mich.
Miller, S. C., Matson Navig. Co., San Francisco, Calif.
Neagle, R. J., Allis-Chalmers Mfg. Co., Hyde Park, Mass.
Neville, S., Min. of Aircraft Production, London, England
Nielsen, R. A., Westinghouse Res. Labs., East Pittsburgh, Pa.
Orrick, T., Kauai Elec. Co., Ltd., Kauai, T. H.
Patterson, R. J. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Purifoy, G. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Rodney, H. A., E. I. du Pont de Nemours & Co., Wilmington, Del.
Sandman, D. (Reelection), Sandman Elec. Motor Co., Boston, Mass.
Saslaw, M. R., Cons. Engr., New York, N. Y.
Scott, A., Pac. Gas & Elec. Co., San Francisco, Calif.
Scott, G. W., Jr., Armstrong Cork Co., Lancaster, Pa.
Shearer, H. F. (Reelection), Can. Line Materials, Scarboro Junction, Ont., Can.
Shimp, E. H., Pub. Serv. Elec. & Gas Co., Irvington, N. J.
Sinclair, D. B., General Radio Co., Cambridge, Mass.
Stroessler, H. M. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Swift, L., Shawinigan Water & Pr. Co., St. Roch, Que., Can.
Taverner, H. B. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Tuthill, O. W., N. J. Bell Tel. Co., Newark, N. J.
Vaughn, D. W., Thirlwell, Henderson, Marine Elec. Co., Evansville, Ind.
Walker, H. K., S. C. Elec. & Gas Co., Columbia, S. C.

50 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Allen, J. P., Gen. Elec. Co., Boston, Mass.
Britt, F. L., Corning Glass Works, Corning, N. Y.
Clark, R. G., Gen. Elec. Co., Boston, Mass.
Crane, L. E., Gen. Elec. Co., Boston, Mass.
Creamer, E. C., Hyde Windlass Company, Bath, Me.
Cushman, P. G., Gen. Elec. Co., Schenectady, N. Y.
Day, G. C., Gen. Elec. Co., West Lynn, Mass.
Finnian, B., Southern New Eng. Tel. Co., New Haven, Conn.
Guyer, E. M., Corning Glass Works, Corning, N. Y.
Hansen, W., Gen. Elec. Co., Boston, Mass.
Hoagland, R. G., Allis-Chalmers Mfg. Co., Hyde Park, Mass.
James, H. E., Gen. Elec. Co., Schenectady, N. Y.
Kennison, J. A., Fitzgibbons Boiler Co., Inc., Owego, N. Y.
Lindquist, A. J., Jr., Asso. Spring Corp., Forestville, Conn.
Quaries, G. G., Harvard Univ., Cambridge, Mass.
Saunders, S. E., Allis-Chalmers Mfg. Co., Hyde Park, Mass.
Sothman, E. P., Jackson & Moreland, Boston, Mass.
Spring, A. L., 1st Ind. Corp., Roxbury, Mass.
Steward, J. F., Sou. New Eng. Tel. Co., New Haven, Conn.
Weis, B. E. T., Jr., Lewis Engg. Co., Naugatuck, Conn.
Westgard, J. A., 1st Ind. Corp., Boston, Mass.
Wheeler, W. R., Univ. of Rochester, Rochester, N. Y.

2. Middle Eastern

Asnin, J. I., U. S. Bur. of Ord., Washington, D. C.
Braithwaite, C. H., Jr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Cline, R. W., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio
Colombo, C. C., Wright Field, Dayton, Ohio
Cortelli, J. A., Clark Cont. Co., Cleveland, Ohio
Davenport, W. H., Jr., Westinghouse Res. Labs., East Pittsburgh, Pa.
Davis, R., Lieut. U. S. Army, Washington, D. C.
Ehlers, E. M., Wright Field, Dayton, Ohio
Fennell, F. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Ferguson, J. S., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Foulds, W. L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Fox, K. H., Bendix Radio Corp., Red Bank, N. J.
Fulford, H. G., Beth. Steel Co., Baltimore, Md.
Gerwin, T. G., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Goodwin, W. J., Nat. Adv. Comm. for Aer., Cleveland, Ohio
Gray, J. M., Maryland Dry Dock Co., Baltimore, Md.
Hall, R. C., Delaware Pr. & Lt. Co., Wilmington, Del.
Hunt, J. H. (Reelection), Toledo Edison Co., Toledo, Ohio
Knepper, M. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Krinic, E. M., Metropolitan Edison Co., Easton, Pa.
Leak, W. H., Cincinnati Shaper Co., Cincinnati, Ohio
Levinson, E. G., U.S.C.G. Detachment, East Pittsburgh, Pa.
MacGillivray, R. H. (Reelection), Westinghouse Elec. Int. Co., Washington, D. C.
McArtor, W. A., Amer. Tel. & Tel. Co., Philadelphia, Pa.
Neyhouse, G. A., Gen. Motors Corp., Dayton, Ohio
Nickle, F. V., Nat. Adv. Com. for Aero., Cleveland, Ohio
Ramer, T. W., General Armature Corp., Mill Hall, Pa.
Sabo, J. H., Fiberglas Corp., Newark, Ohio
Smith, H. J., Wright Field, Dayton, Ohio
Stark, G. D., Allis-Chalmers Mfg. Co., Pittsburgh, Pa.
Wentker, F. W., Radio Corp. of America, Camden, N. J.
Zimmerman, H. B., Phila. Elec. Co., Philadelphia, Pa.

3. New York City

Gordon, E. F., Phelps Dodge Copper Prod. Corp., New York, N. Y.
Holmes, W. K., Mun. Pr. Plant, Freeport, N. Y.
Jones, S. F. G., N. Y. Tel. Co., New York, N. Y.
Levinson, S., Okonite-Callender Cable Co., Inc., Paterson, N. J.
McDonnell, F. W., Jersey Cen. Pr. & Lt. Co., Asbury Park, N. J.
Osgood, R. H. (Reelection), Okonite Co., New York, N. Y.
Peres, P., Corp. de Fom. de la Prod., New York, N. Y.
Purpura, S. J., U. S. Navy, New York, N. Y.
Schulz, C. L. (Reelection), American Can Co., Jersey City, N. J.
Scutt, J. M., Ford Inst. Co., Long Island City, N. Y.
Smith, A. G., Weston Elec. Inst. Corp., Newark, N. J.
Thompson, A. E., Ebasco Services, Inc., New York, N. Y.
White, F. V., Okonite-Callender Cable Co., Inc., Paterson, N. J.

4. Southern

Albright, A. L., Cities Serv. Ref. Corp., Lake Charles, La.
Bettis, C. E., Tenn. Eastman Corp., Knoxville, Tenn.
Bradford, J. C., Memphis Lt., Gas & Water Div., Memphis, Tenn.
Campbell, J. O., Tenn. Eastman Corp., Oak Ridge, Tenn.
Custer, C. M., Southwest Pr. Pool, Little Rock, Ark.
Henry, R. W., Tenn. Val. Auth., Knoxville, Tenn.
Lloyd, T. F., Post Engrs. Office, Barksdale Field, La.
Loscalzo, V. J., Gen. Elec. Co., Atlanta, Ga.
McKeever, C. A., Tenn. Eastman Corp., Oak Ridge, Tenn.
Rockwell, T., III, Tenn. East. Corp., Oak Ridge, Tenn.
Williamson, W. W., Tenn. Eastman Corp., Knoxville, Tenn.

5. Great Lakes

Adkins, R. M., Purdue Univ., Lafayette, Ind.
Bauer, C. A. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Bauerschmidt, G. J. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Bydal, C. B., Commonwealth Edison Co., Chicago, Ill.
Dring, M. J., South Bend Elec. Co., South Bend, Ind.
Fletcher, E. L., Cen. Ill. Elec. & Gas Co., Rockford, Ill.
Floor, H., Harza Engg. Co., Chicago, Ill.
Fransen, N. O., Commonwealth Edison Co., Chicago, Ill.
Greenwald, H. H., Pub. Serv. Co. of N. Ill., Chicago, Ill.
Kibler, R. S., Cen. Ill. Elec. & Gas Co., Rockford, Ill.
Klasmer, C. M., Laclede Steel Co., Alton, Ill.
Miller, A. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Nelson, C. E., Pub. Serv. Co. of N. Ill., Chicago, Ill.
Neteland, C. L., Commonwealth Edison Co., Chicago, Ill.
Patterson, G. H. (Reelection), Pub. Serv. Co. of N. Ill., Maywood, Ill.
Ryan, E. A. (Reelection), Commonwealth Edison Co. Chicago, Ill.
Taylor, J. W., Diamond Chain & Mfg. Co., Indianapolis, Ind.
Trompeter, J. J., Trompeter Elec. Co., Peoria, Ill.
Ungrodt, A. L. (Reelection), Commonwealth Edison Co., Chicago Ill.
Vielmetti, C. J., Pub. Serv. Co. of N. Ill., Joliet, Ill.
Wadsworth, W. J., Harza Engg. Co., Chicago, Ill.
Westrich, C. J., Sears Roebuck & Co., Chicago, Ill.
Williams, E. W., Kyle Corp., South Milwaukee, Wis.
Zipay, A. E. (Reelection), Commonwealth Edison Co., Chicago, Ill.

6. North Central

Carman, C. C., Univ. of Colo., Boulder, Colo.
Kinnear, T. H., Pub. Serv. Co. of Colo., Denver, Colo.
Langford, J. L., U. S. Bur. of Reclamation, Denver, Colo.
Little, A. A., N. W. Bell Tel. Co., Omaha, Nebr.

7. South West

Ausman, J. G., Southwestern Pub. Serv. Co., Amarillo, Texas
Baker, L., Dallas Pr. & Lt. Co., Dallas, Texas
Bialock, L. B., Texas Pr. & Lt. Co., Dallas, Texas
Chadwick, D. N., Dallas Pr. & Lt. Co., Dallas, Texas
Cobb, C. C., Magnolia Pet. Co., Beaumont, Texas
Debney, G. C., Magnolia Pet. Co., Beaumont, Texas
Eichner, R. M., Gen. Elec. Co., San Antonio, Texas
Fontaine, J. E., Graybar Elec. Co., Beaumont, Texas
Gager, A. F., Gulf States Util. Co., Beaumont, Texas
Heiter, D. G., Emerson Elec. Mfg. Co., St. Louis, Mo.
Hodson, H. O., Southwestern Pub. Serv. Co., Amarillo, Texas
Long, W. H., E. I. du Pont de Nemours & Co., Pryor, Okla.
Nichols, R. L., Sr., Magnolia Pet. Co., Beaumont, Texas
Osborn, E. M., Osborn Elec. & Sup. Wks., Muskogee, Okla.
Reddoch, T. E., Magnolia Pet. Co., Beaumont, Texas
Slocum, J. T., Gulf States Util. Co., Beaumont, Texas
Straughn, W. L., Sr., Straughn Radio & Elec. Serv., Beaumont, Texas
Ward, F. R., Emerson Elec. Mfg. Co., St. Louis, Mo.
Woeltge, F. W., Emerson Elec. Mfg. Co., St. Louis, Mo.

8. Pacific

Arnold, W. H., L. A. Water & Pr. Dept., Los Angeles, Calif.
Dial, W. C., U. S. Navy Yard, Mare Island, Calif.
Ford, R. O., Los Angeles Water & Pr. Dept., Los Angeles, Calif.
Gielow, W. R., Pac. Gas & Elec. Co., San Francisco, Calif.
Ingalls, H. M., Cons. Vultee Aircraft Corp., Vultee Field, Calif.
Leffmann, W. W., Allis Chal. Mfg. Co., Los Angeles, Calif.
Lewis, T. E., Western Pipe & Steel Co. of Calif., San Pedro, Calif.
McNaughton, C. C., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.
Miller, R. D., U. S. Naval Drydocks, San Francisco, Calif.
O'Brien, R. P. (Reelection), Calif. R.R. Com., San Francisco, Calif.
Pease, H. E., L. A. Water & Pr. Dept., Los Angeles, Calif.
Percy, F. W., Con. Vultee Aircraft Corp., Tucson, Ariz.
Reed, J. F., Southern Calif. Tel. Co., Los Angeles, Calif.
Rubright, E. C., Cons. Vultee Aircraft Co., San Diego, Calif.
Sauer, H., Douglas Aircraft Co., Los Angeles, Calif.
Struck, D. W., Cons. Vultee Aircraft Corp., San Diego, Calif.
Tickner, H. E., Pac. Gas & Elec. Co., San Francisco, Calif.
Tregaskis, L. M., Winton Lumber Co., Martell, Calif.
Wilson, A. P., U. S. Naval Drydocks, San Francisco, Calif.
Yarbrough, C. T., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.

9. North West

Davis, R. F., City of Tacoma, Tacoma, Wash.
Kaiser, K. H., Puget Sound Pr. & Lt. Co., Deitringer, Wash.
Kennell, D. A., Pac. Tel. & Tel. Co., Portland, Ore.
McLean, J. F., Williamette Iron & Steel Corp., Portland, Ore.
McLean, W. S., Williamette Iron & Steel Corp., Portland, Ore.
Measure, A. J., Mont. Pr. Co., Great Falls, Mont.
Morrison, E. B., Ore. Ina. Rat. Bur., Portland, Ore.
Smith, W. D., Port. Gen. Elec. Co., Portland, Ore.
Wetterborg, H. A., Port. Gen. Elec. Co., Portland, Ore.
Whiteley, T. B., U. S. Navy Yard, Bremerton, Wash.

10. Canada

Bainbridge, A. S., Porritt & Spencer Co., Ltd., Hamilton, Ont., Can.
Bowen, E. K., Can. Gen. Elec. Co. Ltd., Toronto, Ont., Can.
Raymond, J. E., Can. Westinghouse Co., Ltd., Hamilton, Ont., Can.
Shirley, Mrs. Q. H., Guthrie Lab. Mach. Co., Ltd., Windsor, Ont., Can.
Vanderleck, J. M., Nat. Res. Council, Ottawa, Ont., Can.
Williamson, W. A., Can. Gen. Elec. Co., Ltd., Toronto, Ont., Can.

Elsewhere

Castorina, D., Siam di Tella, Ltda., Buenos Aires, Arg., S. A.
DiLuciano, V. F. A., Siam di Tella, Ltda., Buenos Aires, Arg., S. A.
Giuliani, J. C., Siam di Tella, Ltda., Buenos Aires, Arg., S. A.
Sarwal, S. S. D. C., C. A. V., Ltd., London, England
Singh, B., Delhi-Polytechnic, Delhi, India
Vucetich S., D., Cia. Chil. de Elec., Ltda., Santiago, Chile, S. A.

Total to grade of Associate

United States and Canada, 161

Elsewhere, 6

OF CURRENT INTEREST

ASA Announces Plan to Widen Scope of Activities

Because of the growing importance of standards for consumer goods, removal of the present restrictions which limit the work of the American Standards Association to the engineering field was authorized by the ASA board of directors at its annual meeting held in New York, N. Y., December 8, 1944. Such increased scope will necessitate reorganization of the ASA so that it can handle any standard or standardization project which deserves national recognition, whether in the field of engineering, accounting, business practice, or consumer goods.

Officers for 1945, announced at the meeting, are:

Henry B. Bryans, executive vice-president and director, Philadelphia Electric Company, re-elected president; George S. Case, chairman of the board, Lamson and Sessions Company, re-elected vice-president; H. S. Osborne, American Telephone and Telegraph Company, re-elected chairman, Standards Council, which is in charge of all ASA technical work; E. C. Crittenden, National Bureau of Standards, re-elected vice-chairman, Standards Council.

Speakers at the meeting included Rear Admiral E. L. Cochrane, chief, Bureau of Ships, United States Navy, who discussed the meaning of standardization to the Navy; Henry B. Bryans, executive vice-president of the Philadelphia Electric Company and President of the ASA; and H. S. Osborne (F '21) chairman of the Standards Council, who reported on the ASA's technical work for the year.

The accomplishments of the ASA in the past year, as in 1943, were concerned mainly with the war effort. More than 50 special war jobs were completed including 21 radio standards, 25 war standards in the photographic field, and special war specifications for occupational clothing which have now reached 21 in number. An interesting footnote to the 1943 meeting, at which participation in the organization of a United Nations Standards Body was authorized, was provided by receipt of a communication from the national standardizing body of France re-establishing relations with the United States and asking to be brought up to date on the work of the past few years.

During 1944 the ASA approved 157 standards, the highest number on record. Of the 66 standards handled under the emergency procedure established for war standards, the largest number, 27, related to the safety of workers. Most of these were concerned with protective clothing and shoes for workers. Under the regular procedure of the ASA, standards were developed to cover specifications and tests of a wide range of materials, standardizations of films and photographic processes, various safety measures, and a guide to municipal officials in the preparation of administrative sections of building codes.

Although, during the war period, the ASA has directed its work toward industrial standards of immediate use, a large postwar increase in the volume of standards for consumer goods is anticipated and the basic planning for the future of the ASA is being made with that end in mind. As an indication of the increased importance of standardization problems in the United States, a conference is being called at the request and in the name of the Secretary of Commerce of the United States, by the visiting committee of the National Bureau of Standards, for the purpose of recommending action that will meet a large volume of criticisms received by the Department of Commerce, leveled at alleged inadequacy of function and lack of coverage by the existing organizations in the standardization field. To cope with this contingency, the ASA is developing a broad program which, it believes, will prove acceptable to industry, to consumers, and to the Government.

WAR PROGRAM

Troopships Provided With Package Power Plant

A "packaged" power plant, consisting of a 3,500-horsepower turbine, generator, and condenser, is being manufactured by the Westinghouse Electric and Manufacturing Company for installation on troopships and cargo vessels. This "package" is complete, even to the lubricating oil system, pumps, and piping, and need only be connected.

The new ships in which these plants are used are twin screw with each shaft turned by a 3,300-horsepower slow-speed 80-cycle synchronous motor. Auxiliary power is provided by separate generating units. The excitation for the generators is controlled by a rotating regulator of the Rototrol type which permits smaller normal excitation power but provides a rapid boosting of excitation in emergencies. The system provides an automatic control of stability.

Distinguished Service Award for Moore School. In recognition of the value of its research and development work in furthering the war effort, the Moore School of Electrical Engineering of the University of Pennsylvania has been granted the Army Ordnance Department's Distinguished Service Award.

Rural Electrification Increased. With the addition of more than 400 new farm customers during the first nine months of 1944, the Public Service Company of Northern Illinois has pushed the total number of farm and rural units served with electricity past the 24,800 mark and has lengthened its rural power lines by 50 miles. These new farm customers are being added wherever applicants can justify their wartime need for electricity under War Production Board regulations. As evidence of the greater use of electricity in the production of foods for the war, the company cites an average increase for the year of 181 kilowatt-hours per farm customer. Among the electric work-saving farm equipment in use in northern Illinois are chick and pig brooders, milking machines, water pumps, and grain elevators.

INDUSTRY

New System of Modulation Presented at IRE Meeting

Development of a system of pulse time modulation, applicable to wire and radio transmission, including broadcasting and television sound channels, was disclosed at a meeting of the Institute of Radio Engineers in a paper by E. Labin and E. M. Deloraine. The authors are connected with the Federal Telephone and Radio Laboratories, an associate of the International Telephone and Telegraph Corporation.

Pulse time modulation consists essentially in transmitting intelligence by pulses of constant amplitude and duration. The instantaneous amplitude of the voice is translated into a variation of time intervals of successive pulses, the rate of this variation corresponding to the instantaneous frequency of the signal. Its main advantages include simplification derived from the use of more rugged repeaters, capable of operating on trigger action, thereby materially reducing the usual requirements for stability, distortion, and noise. Further, distortions introduced in the different repeaters are not cumulative.

Research and development work was started in 1937 on the basis that modern transmission technique at high frequencies was confronted with the fact that much wider bandwidths per channel are available than strictly required by the elements of most signals to be transmitted. Compared with amplitude modulation and frequency modulation, pulse time modulation appears particularly promising for application to multichannel, coaxial cable, telephone, telegraph, and facsimile transmission systems, also to point-to-point radio and ultrahigh frequency broadcasting and to television sound channels.

Gas Turbine Explained in Movie. The story of the development and operation of the gas turbine, new source of prime power, is told in a movie entitled "Tornado in a Box" which has just been released. The film, which is 16 mm for use on sound projectors only, may be either borrowed without charge or purchased by interested engineering or industrial groups from the Allis-Chalmers Manufacturing Company, Milwaukee 1, Wis. "Tornado in a Box" contains no advertising and is the third in a series, preceding titles being "The Magic of Steam" and "The Surface Condenser."

Mercury Lamp Improves Hangar Lighting

A new three-kilowatt mercury lamp, seven times larger than any air-cooled mercury lamp heretofore available, which answers the lighting requirements of the vast working spaces of blimp hangars, airplane factories, and steel mills, is being manufactured by the Westinghouse Electric and Manufacturing Company. In successfully meeting the extreme mounting-height conditions of 130 feet in this blimp hangar, the new lamp casts relatively little shadow. The five-foot-long tubular lamp delivers a total of 120,000 lumens in comparison with the 33,000 lumens of a 1,500-watt incandescent lamp. Used for both direct and indirect lighting, the lamp is especially suited to direct lighting for high-bay areas where its powerful glare is ordinarily beyond the line of vision

SAFETY

These items are compiled by the AIEE committee on safety, W. R. Smith, chairman.

This column inaugurates a service which the committee on safety anticipates will prove of value to members of the Institute whether or not they are identified in a specific way with the field of accident prevention.

No engineer can move very far in the fields of design, construction, operation, or maintenance without developing a realization of the extent to which his plans and actions are influenced by safety considerations. Certainly, any design that is not safe to use and maintain is not representative of best engineering in the thinking of today, no matter how efficient or usable the particular device or machine may be. In like manner, construction, operation, and maintenance procedures and practices should be abreast of the times and in keeping with the trends in such matters which have been dictated by both experience and the greatly intensified effort which is being made to foresee hazards to personnel and either eliminate them or prepare in advance to meet them. Human life is too great a price to pay for failure to understand and apply the fundamental principles which underly the safe use of electric energy in all of its phases from generation through transmission and distribution to consumption at the command of the users in homes, industries, and commercial establishments.

It will be the purpose of this column to provide means for bringing to the attention of members of the Institute items of news and information in the field of electrical safety.

ELECTRIC SHOCK

Electrical engineers in all phases of their professional life and in their outside contacts with groups and individuals can render a real service to the cause of safe use of electricity if they will avail themselves of opportunities to disseminate knowledge and a better understanding of the conditions under which even low voltages can be dangerous. This does not mean the giving of prepared talks—although such talks to parent-teachers associations and many other groups can be of great value—but rather seeing to it that obvious carelessness which arises out of ignorance does not go unnoticed and uncorrected. The low-voltage fatalities that occur usually are the consequence of lowered skin resistance from moisture or because of large contact area. The fact that such victims have received "mild" shocks on one or more occasions when conditions were favorable often serves but to "condition" them for the subsequent serious happening by giving a false sense of security. The price that later is paid for a moment of carelessness or overconfidence is too great.

FATALITIES IN ELECTRIC LIGHT AND POWER INDUSTRY

A recent report by D. C. Stewart, of the Niagara Hudson Power Corporation to the accident-prevention committee of the Edison Electric Institute on the causes of fatalities in the electric light and power industry in 1943 is called to the attention of all engineers in that field and that of general industry. This report shows that electric shocks and burns continue to be the power industry's number-one problem, despite the fact that the way to prevention is known to be through the proper use of rubber protective equipment and observance of safe working practices and procedures. This report appears in the October 1944 issue of Edison Electric Institute *Bulletin*.

RESUSCITATION TECHNIQUES

Pole-Top Resuscitation. Engineers in the electric light and power industry and those with railroads or large industrial organizations employing linemen who are not already informed will find pamphlet *K*8 of the Edison Electric Institute helpful to an understanding of the purpose and the techniques of this method. This contribution to the field of artificial respiration, which was made by the Duquesne Light Company some years ago, shows the way to employ, with the desired promptness, the principles of Schafer's prone-pressure method to the special needs of the lineman on the pole.

Eve's Rocking Method. While not new in principle, this procedure is particularly suited to the need for prolonged artificial respiration, especially that necessitated by long immersion in cold water. The method is described in an article by Frank C. Eve of Hull, England, who proposed it for use by the British Navy, in the *Journal* of the American Medical Association of April 1, 1944. It is discussed in a recent paper by Cecil K. Drinker, professor of physiology in the Harvard School of Public Health, which appeared in the July 1944 issue of the Oklahoma State *Medical Journal*. The subject of the paper is "The Restoration of Breathing in Emergencies and the Maintenance of Respiration in Nonbreathing Patients." It is important to note that, whereas the pole-top method is truly a first-aid method, the Eve method is more suited to the continuance of artificial respiration for long periods. The prone-pressure method should be employed at once even though a suitable rocking mechanism is available, and then, if by the time the rocking device arrives there is no evidence of recovery, the choice can be made between continuing with prone pressure or placing the victim on the rocking board. The fundamental underlying artificial respiration is that it must be started at once with the least delay.

BIBLIOGRAPHY ON ELECTRICAL SAFETY

The committee on safety is planning a revision of this pamphlet which was first issued in July 1942. The committee would welcome comments on the value of this publication and also suggestions concerning important references that should be included. Copies can be obtained from Institute headquarters, and comments and suggestions should be sent to the committee's secretary, A. B. Campbell, 2 Rector Street, New York 6, New York.

INFORMATION

The chairman of the committee on safety is desirous of having the committee serve the members in any respects that may be consistent with its purposes and scope. Obviously, answers to questions having to do

with local conditions that would have to be investigated, in general, cannot be attempted, but appropriate inquiries may be addressed to the secretary, and effort will be made to supply the desired information.

LITERATURE

There are in the files of the chairman or other members of the committee copies of the literature that are referred to in this column, or the sources of such and other literature that may be of interest are known. Information will be supplied when requested, and in some instances copies may be available for reading and return. Address the secretary.

MEETING OF COMMITTEE

The committee on safety expects to hold a meeting January 23 at 2:00 p. m. during the 1945 winter technical meeting of the Institute. Institute members who are in attendance and are interested are invited.

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 18–22, 1945, New York, N. Y.

American Society for Testing Materials. Spring meeting, February 28, 1945, Pittsburgh, Pa.

American Society of Civil Engineers. Annual meeting, January 17–19, 1945, New York, N. Y.

Canadian Electrical Association. Annual winter conference, January 18–19, 1945, Montreal, Canada.

Edison Electric Institute. Transmission and distribution committee, February 15–16, 1945, Pittsburgh, Pa.; electrical equipment committee, February 14–15, 1945, Cincinnati, Ohio; accident prevention committee, February 15–16, 1945, Cleveland, Ohio.

Institute of Radio Engineers. Winter technical meeting, January 24–27, 1945, New York, N. Y.

Institute of the Aeronautical Sciences. 13th annual meeting, April 1945, Detroit, Mich.

OTHER SOCIETIES •

IES Appoints Technical Secretary

The appointment of Cazamer L. Crouch as full-time technical secretary of the Illuminating Engineering Society has been announced. This assignment constitutes one phase of IES plans for the expansion of its technical and research activities.

As technical secretary Mr. Crouch will act as consultant to the technical committees and to the council of IES. His major assignment will be the compilation, writing, and publication of the IES Illumination Design Handbook.

Mr. Crouch will also be available for assistance in the society's newly established research program, under the direction of the board of research trustees. Newly elected officers of this board are:

P. H. Daggett, dean of the college of engineering, Rutgers University, New Brunswick, N. J. chairman.

A. H. Nicoll, president, the Graybar Electric Company, New York, N. Y. treasurer.

A. Dexter Hinckley, secretary.

The board, a completely autonomous group, sponsored though not controlled by IES, will act as trustees of the IES research fund. Individual research projects are expected to be carried out with the co-operation of the research laboratories of leading universities and other institutions.

ASRE Elects 1945 Officers

J. F. Stone, manager of the refrigeration division, Johns-Manville Corporation, New York, N. Y., has been elected president of The American Society of Refrigerating Engineers according to a recent announcement.

Other officers elected are: Charles S. Leopold, consulting engineer, Philadelphia, Pa., and Roland H. Money, chief refrigeration engineer, the Crosley Corporation, Cincinnati, Ohio, as vice-presidents; John G. Bergdoll, Jr., chief engineer, York Corporation, York, Pa., as treasurer; and, as directors for three-year terms, B. H. Jennings, professor of mechanical engineering, Northwestern University, Evanston, Ill.; Charles S. Neeson, chief engineer of the cooling division, Airtemp division, Chrysler Corporation, Dayton, Ohio; John S. Forbes, president, Superior Valve and Fittings Company, Pittsburgh, Pa.; Warren W. Farr, president and treasurer, Refrigeration Maintenance Corporation, Cleveland, Ohio; and C. Hill Garrison, C. H. Garrison Company, Kansas City, Mo.

EDUCATION • • •

Engineering Scholarships Offered. Ten scholarships, now valued at $1,850 each, will be awarded for an engineering education at the Carnegie Institute of Technology, Pittsburgh, Pa., according to an announcement of the Westinghouse Electric and Manufacturing Company, sponsor of the 1945 George Westinghouse Scholarship contest. The contest is open to all senior high-school boys in the United States who present a good high-school scholastic record, are able to meet the Carnegie Institute of Technology's entrance requirements, and who did not compete in the 1944 competition. Applications will be accepted until February 1, 1945, and the tests will be administered by the college entrance examination board on April 7, 1945.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Armature-Winding Resistance

To the Editor:

The a-c resistance of an armature winding is greater than the d-c resistance on account of the eddy currents produced in the conductors by the slot-leakage flux. The extra loss caused by these eddy currents can be computed with excellent precision by means of hyperbolic functions. The extra loss factor depends upon the frequency, the geometrical arrangement of the conductors, and their resistivity. If the resistivity is increased, the extra loss factor is reduced. That is, the extra loss factor for an armature winding is less when the winding is hot than when it is cold. For a well-designed armature winding in which the eddy-current loss is not excessive, the extra loss factor can be computed from the first terms of the series expansions of the hyperbolic functions. This is a common procedure. For example see reference 1. The first term of the hyperbolic series varies as the inverse square of the resistivity. Since the increase in the resistance caused by the a-c equals the d-c resistance (which varies directly with the resistivity) multiplied by the extra loss factor (which varies inversely as the square of the resistivity), the increase in the resistance varies inversely as the first power of the resistivity. Consequently, in general:

$$R_{ac} = R_{dc} + \frac{K}{\rho}$$

where K/ρ, which equals $(R_{ac} - R_{dc})$, is due to the extra loss caused by the eddy currents. The resistivity, ρ, varies with the temperature,

$$\rho \text{ at } t_2 = \frac{234.5 + t_2}{234.5 + t_1} \times (\rho \text{ at } t_1)$$

Let the subscripts 1 and 2 indicate resistances at temperatures t_1 and t_2. The a-c resistance at temperature t_2 is:

$$R_{ac} = \frac{234.5 + t_2}{234.5 + t_1} R_{dc1} + \frac{234.5 + t_1}{234.5 + t_2} (R_{ac1} - R_{dc1})$$

Thus the a-c resistance of an armature winding at a temperature t_2 can be computed easily from the a-c resistance and the d-c resistance of the winding at a tempera ure t_1. This correction for the effect of temperature is applied to the transformer in reference 2. The correction can be used in many situations where the eddy-current loss is not excessive.

REFERENCES

1. Reduction of Armature Copper Losses, **Ivan H. Summers.** AIEE *Transactions*, volume 46, 1927, February section, pages 101–08.

2. Magnetic Circuits and Transformers (book), **Electrical-engineering staff,** Massachusetts Institute of Technology, Cambridge, Mass.

WALDO V. LYON (F '33)

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NEW BOOKS . . .

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Basic Structures. By F. R. Shanley. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 392 pages, illustrated, 8¼ by 5½ inches, cloth, $4.50. (ESL.)

The opening chapters describe simple kinds of forces and force systems and develop the methods of transmitting these forces through space. From that point on the arrangement has been dictated by the actual development and analysis of the structure as a means of force transmission with particular emphasis on the physical action involved. The mathematical treatment has been kept as simple as possible. Special application is made to the design and analysis of aircraft structures.

Chemical Industry. By J. Perry. Longmans, Green and Company, New York, N. Y., and Toronto, Ont., Canada, 1944. 128 pages, illustrated, 8½ by 6 inches, cloth, $1.75. (ESL.)

Beginning with a brief survey of the history of chemistry in ancient times, this small book continues with the growth of the chemical industry in the United States from early times to the present. Important products and processes are discussed in a simple concise manner, including a chapter on synthetic products. The volume is one of a series covering the important industries of this country.

Direct-Current Circuits (Rochester Technical Series). By E. M. Morecock. Harper and Brothers, New York, N. Y., and London, England, 1944. 387 pages, illustrated, 9½ by 6 inches, cloth, $3.25. (ESL.)

Designed as a basic course for elementary study, this text provides selected laboratory experiments and a variety of problems for review purposes. A working knowledge of algebra and logarithms but not calculus is required. The separate chapters deal with elementary electric circuits, magnetism and electromagnetism, instruments and measurement methods, power and energy, conductors and insulation, batteries, the magnetic circuit, electromagnetic induction, capacitance, and electrostatics.

Electronics. By J. Mills. D. Van Nostrand Company, New York, N. Y., 1944. 178 pages, illustrated, 8 by 5 inches, cloth, $2.25. (ESL.)

The simple characteristics of electrons, both in nature and as used by science, are discussed in the introductory chapters. The following section describes the evolution and operation of the more important kinds of electron tubes, vacuum or gas-filled. The last section is devoted to explanation of various electronic devices for television, electron microscopy, ultrahigh-frequency apparatus, and the cyclotron. The book is designed for the "intelligent layman."

Infrared Spectroscopy. By R. B. Barnes, R. C. Gore, U. Liddel, and V. Z. Williams. Reinhold Publishing Corporation, New York, N. Y., 1944. 236 pages, illustrated, 9¼ by 6 inches, fabrikoid, $2.25. (ESL.)

This work is a "partial answer to the increasing demand for information concerning the industrial applications of infrared spectroscopy." The theory of infrared absorption and its relation to molecular structure are discussed to provide the background for a description of techniques useful in analysis. A "library" of 363 representative spectra of organic compounds is presented for comparison with those obtained from unknown compounds. A bibliography of over 2,500 references is given. The material, except the bibliography, was first published in *Industrial and Engineering Chemistry.*

Man's Fight to Fly. By J. P. V. Heinmuller, foreword by E. Rickenbacker. Funk and Wagnalls Company, New York, N. Y., and London, England, 1944. 366 pages, illustrated, 11 by 8 inches, fabrikoid, $6. (ESL.)

The author of this book has for many years been observer and chief timer for the National Aeronautic Association, in which capacity he has timed most of the transatlantic and round-the-world flights. He has known nearly all the prominent flyers. His book gives his personal recollections of many world-record flights, illustrated by photographs from his collection. A chronology of aviation from 1483 to 1939 points the outstanding steps in development.

Men of Science in America. By B. Jaffe. Simon and Schuster, New York, N. Y., 1944. 600 pages, illustrated, 9 by 6 inches, cloth, $3.75. (ESL.)

A broad picture of the growth of science in the United States is presented by means of a series of biographical sketches. The lives and achievements of 19 of the foremost American scientists are viewed against their historical background, with emphasis on the influence of scientific discovery upon the social structure of the country. The future of science in America is suggested briefly in the last chapter, and a full list of sources and reference material is included.

Methods of Advanced Calculus. By P. Franklin. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 486 pages, illustrated, 8½ by 5¼ inches, cloth, $4.50. (ESL.)

This textbook is designed for students whose major field of interest is engineering, mathematics, or science, but it also may serve the practicing engineer or applied scientist as an introduction to the more formidable mathematical treatises. The two principal objectives of the book are: to refresh and improve the student's technique in applying elementary calculus and to present those methods of advanced calculus most needed in applied mathematics.

Military and Commercial Aircraft Hydraulics. By R. N. Greif. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1944. 113 pages, illustrated, 8¼ by 5¼ inches, cloth, $2. (ESL.)

This practical book describes in detail the basic units of hydraulic systems, beginning with elementary applications and working up to complete systems for aircraft purposes Maintenance, inspection, trouble shooting, and repair are covered in the later chapters, and a separate chapter is devoted to an explanation of hydraulic plumbing details. The book is intended both as a text and a reference manual for the practical mechanic.

Extrusion of Metals. By C. E. Pearson, with a foreword by R. Genders. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 205 pages, illustrated, 8¼ by 5½ inches, cloth, $3.75. (ESL.)

We have here a concise account of extrusion practice relating to different classes of work and materials, based on the widely scattered information available in the literature and on the author's own studies. Chapters on flow phenomena in the process and on the influence on the extrusion of metals of such factors as temperature and the speed and extent of deformation are included. Impact extrusion also is discussed.

PAMPHLETS . . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

An Engineering Interpretation of the Economic and Financial Aspects of American Industry, Volume VI, the Electronic Industry. George S. Armstrong and Company, Inc., 52 Wall Street, New York, N. Y. Limited number available upon request. 72 pages.

Accident Rates in the Machinery and Electrical Equipment Industry, 1943. National Safety Council, 20 North Wacker Drive, Chicago 6, Ill., 11 pages.

Flexible Shaft Handbook. Second edition. S. S. White, 10 East 40th Street, New York 16, N. Y., 256 pages.

Loans To Small Business. Smaller War Plants Corporation, Washington, D. C., 15 pages.

Lighting Specific for Tobacco Stripping, Unloading, and Auction Warehouse Space, 5 pages. **Lighting for Shipyards,** 12 pages. **Lighting for the Synthetic Rubber Industry,** 10 pages. **Lighting Specific for Railroads,** 22 pages. **Protective Lighting,** 21 pages. **Lighting for the Hospital of Today,** 24 pages. **Lighting for the Oil Refining Industry,** 26 pages. Holophane Company, 342 Madison Avenue, New York, N. Y., no charge.

Postwar Surveys of the Packaging Possibilities of the Electrical Radar and Radio Equipment Industry. National Paper Box Manufacturers Association, Philadelphia, Pa., 5 pages.

Corrosion. The International Nickel Company, Inc., 67 Wall Street, New York 5, N. Y., 54 pages.

Unemployment Insurance in the Second Year of War. State of New York Department of Labor, Albany, N. Y., 28 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Evaluation of Electric Distribution Losses in Terms of Generating-Station-Capacity Investment

M. MORTARA
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ELECTRIC distribution losses affect the economy of a system in two ways: (*a*) by making it necessary to produce, over any period of time, in addition to the energy required by the load, the amount of energy absorbed by the losses during that same period, or "energy losses"; (*b*) by requiring, at the time of the peak, the availability of a generating capacity which exceeds the simultaneous value of total load by the coincident amount of power absorbed by the distribution losses, or "power losses." These two aspects both should be taken into consideration in planning a new electric system or in expanding an existing system.

When the unit cost of energy is known, the economic evaluation of factor *a* requires only the knowledge of the load curve at various times of the year, so that the yearly loss of energy may be determined with sufficient approximation. The economic evaluation of factor *b*, on the other hand, is much less definite, because it is affected by multiple and sometimes variable conditions, which must be properly considered. The purpose of the present paper is to indicate the principal among these conditions and to outline a procedure for the correct economic evaluation of power losses.

Conditions Affecting the Economic Value of Power Losses

The generation peak of an electric system independent from outside sources of power will coincide with the peak load; if, furthermore, the power is supplied by thermoelectric sources, it will be only necessary for the installed generating capacity at any time to be sufficient to take care of the expected peak load. It is obvious that, in a system of this type, a reduction of peak power losses would produce an equal reduction in the requirements of generating capacity.

The existence of interconnections with other systems capable of supplying energy during the period of the yearly peak, but not at other times, might change that condition, making the generation peak coincident with a lower load. In this case, the power losses affecting the requirements of generating capacity will be correspondingly lower, varying approximately as the square of the kilovolt-ampere load. A similar effect may come from the presence of mixed power sources, part thermoelectric and part hydroelectric, and conditions may be modified further if the hydroelectric plants are provided with storage ponds or reservoirs, capable of furnishing power to cover the daily peak at any time of the year.

It is clear that the economic value of peak power losses will be greater for the case mentioned first and that it may become relatively small in some of the other cases, where outside or mixed sources of power supply are available.

The cost of installation of new generating capacity, which is one of the factors determining the worth of power losses, is fairly uniform in the various stages of development, when a system is supplied by thermoelectric stations alone. In effect these stations can be built in unit sections, and complete new sections can be added as required.

In the case of hydroelectric supply, however, conditions are different, because there are certain parts of the plant, involving a major quota of the total cost, which have to be completed initially, regardless of the amount of generating capacity installed. The cost of this latter, therefore, will be generally much higher in the initial stage of a new project than for additions made later in order to reach the ultimate capacity for which the plant is designed. Another circumstance to be considered in the case of hydroelectric projects, is that the different and variable characteristics of river flow for various plants in the same system normally will require the total installed capacity to be appreciably higher than the generation peak. This adds to the difficulty of establishing the required time and cost of installation of generating units.

The basic case of an independent thermoelectric system and the procedures for approaching the problem in other cases are discussed in the following sections.

Table I

Interval of Development	Worth of Power Losses: From Equation 9	Worth of Power Losses: From Equation 9′
From G_0 to G_1	$z = 1.53C$	$z = 1.45C$
From G_0 to G_2	$z = 2.40C$	$z = 2.27C$
From G_0 to G_3	$z = 3.72C$	$z = 3.53C$

Worth of Power Losses in an Independent Thermoelectric System

Procedure for the Economic Evaluation

The investigation of the problem and its solution are to be based upon the estimated effect of a variation of power losses on the future requirements of generating capacity. The initial step, therefore, will be the determination of a curve representing the expected growth of system load.

Analyses of statistical data of a number of public utilities show that the long-range trend of the yearly peak load, in a system serving a definite area, can be

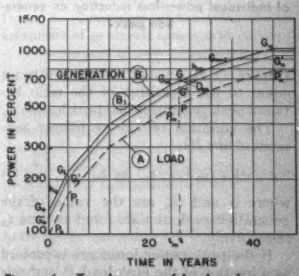

Figure 1. Trend curves of load and generation for an independent electric system, showing effect of different level of power losses on generation peak

Paper 45-6, recommended by the AIEE committee on power generation for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted June 24, 1944; made available for printing November 3, 1944.

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closely represented by a succession of segments of logarithmic parabolas or of exponential curves, with time as exponent. The latter curves, although somewhat less accurate than the former, are generally preferred in planning studies, having the practical advantage of becoming straight lines on semilogarithmic diagrams.

On any such diagram, the trend curve of the peak load will be a polygonal line A composed of rectilinear segments of progressively varying slope (see Figure 1). The equation of any one of the component segments is of the form

$$\log P = \log P_m + (t - t_m) \log h_m \qquad (1)$$

where

t = time in years from the origin
t_m = initial time of the rectilinear portion under consideration
P = peak load at time t
P_m = peak load at time t_m
h_m = factor of growth or ratio between peaks in two consecutive years (constant for the portion of line under consideration)

When a system is designed and developed on the basis of constant percentage of peak power losses, the curve representing the generation peak will be also a polygonal line B, running above A

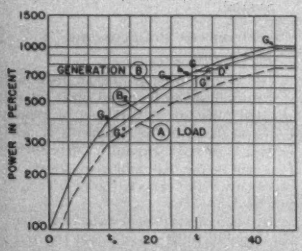

Figure 2. Trend curves of load and generation for an independent system, showing effect of individual power-loss reduction on generation peak

(Figure 1) at constant vertical distance equal to the logarithm of the ratio between peak generation and peak load.

The equation of any rectilinear segment of line B is

$$\log G = \log G_m + (t - t_m) \log h_m \qquad (2)$$

where G and G_m are the values of the generation peak at time t and at time t_m respectively.

If the peak power losses are expressed as a fraction of the peak load P, and d is the ratio between the two, the generation peak will be

$$G = P + dP = P(1+d)$$

For a lower ratio of losses d', the required generation will be reduced to

$$G' = P(1+d') = kG$$

where

$$k = \frac{1+d'}{1+d} \qquad (3)$$

Over the time interval considered, the generation peak of a system having such lower loss ratio will be represented by the equation:

$$\log G' = \log G_m + (t - t_m) \log h_m + \log k \qquad (4)$$

The representative curve is again a polygonal line B_1 located between A and B at constant vertical distance from each of them (Figure 1).

The horizontal distance between B and B_1 is equal to the time lag D_m in reaching a definite generation peak, caused by the power-loss reduction. Its value is constant during each period of uniform growth factor h_m and is obtained from equations 2 and 4 as

$$D_m = \frac{1}{\log h_m} \log \frac{1}{k} \qquad (5)$$

If system conditions represented by B are assumed as basic reference plan, the afore-mentioned time lag will furnish the elements for determining the worth of savings of peak power losses that may be obtained by alternate plans. From equation 5 it is apparent that, for a definite ratio k, the time lag will be greater, the lower the rate of growth and vice versa.

To determine the economic value to be attributed to a reduction of peak power losses, two factors come under consideration:

(*a*). As noted before, a lower level of power losses causes a deferment D in reaching a certain generation peak, in comparison with the basic reference plan. This permits postponing, for that same interval D, the installation of each new generating unit and the outlay of fixed charges thereon.

(*b*). If W designates the capacity of one of the new units to be successively added during a period of growth factor h, the time T elapsing between unit additions in the reference plan, as deduced from equation 2, will be

$$T = \frac{1}{\log h} \log \left(1 + \frac{W}{G}\right) \qquad (6)$$

If h and W remain constant while the peak G progressively increases, the interval T will correspondingly decrease and eventually become equal to the deferment interval D. This would indicate exactly one unit less to be required, at that time, in the lower-loss plan; which means that the installation of a unit would be saved because of the power-loss reduction. This occurrence, however, seldom materializes, since it would require the difference of power losses between the two plans to equal the capacity of a generating unit, within the time of ultimate development of the system. In view of the limitations on the percentages of power losses that can be practically considered, this condition is unlikely to obtain and therefore cannot, generally, be taken into account.

Consequently it appears that, in most cases, the worth of power losses can be evaluated solely on the basis of factor a, that is, the postponement in the outlay of fixed charges on each generating unit of future installation.

The money saving effected because of such deferment, on each of the units to be installed during any period for which a certain value h_n of the growth factor is valid, will be

$$S_n = CWD_n r = \frac{CWr}{\log h_n} \log \frac{1}{k} \qquad (7)$$

where C is the cost per kilowatt of new installed capacity, W the capacity of the unit in kilowatts, D_n the deferment valid over that period, and r the yearly rate of fixed charges (in decimal). The total capacity to be installed during the interval under consideration may be assumed to be equal to the difference between final and initial generation peaks: $(G_{n+1} - G_n)$. Actually there will be some discrepancy, due to the fact that this difference may not be a multiple of the proposed capacity of generating units, but, over the various phases of development of the system, these discrepancies will compensate.

The total savings effected by the alternate plan of lower losses will be the summation of the various values of S_n or, if the index of ultimate development is designated by u:

$$S = \sum_{n=0}^{n=u-1} \frac{Cr(G_{n+1} - G_n)}{\log h_n} \log \frac{1}{k} \qquad (8)$$

In the case under consideration, of uniformly lower percentage of power losses, k is constant and the total reduction of power losses is $(1-k)G_u$. Therefore, the saving per kilowatt of peak power-loss reduction, which can be considered as cost or worth of such losses, will be

$$s = \frac{S}{(1-k)G_u} = \frac{\log 1/k}{(1-k)G_u} \sum_{n=0}^{n=u-1} \frac{Cr(G_{n+1} - G_n)}{\log h_n} \qquad (9)$$

If the values of $(h-1)$ and $(1-k)$ are smaller than 0.10 (as they usually will be in practice), expression 9 can be simplified, without appreciable error, as follows:

$$s = \frac{1}{G_u} \sum_{n=0}^{n=u-1} \frac{Cr(G_{n+1} - G_n)}{h_n - 1} \qquad (9a)$$

Table II

Interval	Total Savings
G_6–G_5	$ 3,371,250
G_5–G_3	6,503,250
G_3–G_1	8,834,500
Total	$18,709,000

thus indicating that s is practically independent from the percentage of loss reduction.

These expressions are valid, as long as the ultimate reduction of power losses is smaller than the capacity of the generating unit assumed to be in use at that time, so that the same number of units is required on the alternate as on the reference plan of development. If there is elimination of one or more units, the corresponding savings should be adequately taken into account.

The value obtained from expressions 9 or 9′ is a weighted average of the costs of power losses in the successive phases, which vary in connection with the growth factor, as noted before.

In the preceding discussion, the effect of a lower level of power losses uniformly

Table III

Number of Unit	Present Value of Power Losses (at Time t_0)	
	Equation 17	Equation 17′
1	$s_1=0.548C$	$s_1=0.546C$
2	$0.365C$	$0.364C$
3	$0.263C$	$0.262C$
4	$0.191C$	$0.190C$
5	$0.183C$	$0.182C$
6	$0.141C$	$0.140C$
7	$0.111C$	$0.110C$
8	$0.089C$	$0.087C$
9	$0.073C$	$0.073C$
10	$0.118C$	$0.118C$
11	$s_{11}=0.088C$	$s_{11}=0.088C$

maintained, has been considered; but, for the complete solution of the proposed problem, it is necessary to investigate the effect of an individual reduction of such losses. Let it be assumed that in a system, originally designed to follow trend line B as shown on Figure 2, developments carried out in a certain phase bring down the power losses, so as to reduce the generation peak at time t_0 from G_0 to $G_0{}''$. The loss reduction of which the effects are to be determined is

$$g=G_0-G_0{}''=(1-k)G_0 \tag{10}$$

If no attempt is made to maintain the lower loss level, and the original loss ratio represented by line B is adopted again, the generation peak at time t, when the growth factor is h_m, can be derived from expressions 2 and 10. Its value G'' will satisfy the equation:

$$\log G''=\log\left(G_m-\frac{g}{h_m{}^{t-t_m}}\right)+(t-t_m)\log h_m \tag{11}$$

represented by line B_2. The ratio between G'' and G is

$$\frac{G''}{G}=1-\frac{g}{G}$$

and becomes equal to unity only for G equal to infinity. The time lag between line B_2 and line B at time t can be determined considering that $\log h_m$ is the tangent of the angle of slope of trend line B, and that the vertical distance between the two lines is $\log[G/(G-g)]$; consequently, their horizontal distance, representing the time lag, will be

$$D''=\frac{1}{\log h_m}\log\frac{G}{G-g} \tag{12}$$

This equation, with the data applicable at the time of installation of each future generating unit, gives the corresponding deferment in the outlay of fixed charges obtainable by the individual loss reduction. For the purpose of the following calculations, it can be assumed, without appreciable error, that units to be used are of uniform capacity, provided this is adequately chosen with regard to initial and ultimate system peak. If such capacity is designated by W and the first unit is assumed to be required in the reference plan at time t_0, the $(n+1)$th unit will be required when the generation peak reaches the value (G_0+nW). The corresponding deferment, due to the loss reduction g, will be

$$D_n{}''=\frac{1}{\log h_m}\log\frac{G_0+nW}{G_0+nW-g}$$

If equation 10 is taken into account and it is posed $G_0/W=p$, the foregoing expression becomes

$$D_n{}''=\frac{1}{\log h_m}\log\frac{p+n}{kp+n} \tag{13}$$

For values of (h_m-1) and $(1-k)$ smaller than 0.10, this equation can be simplified to

$$D_n{}''=\frac{p(1-k)}{(h_m-1)(n+kp)} \tag{13′}$$

The effect of the individual loss reduction is still to produce a deferment in the installation of new generating units; but, over each period of uniform growth, the deferment, instead of being constant as in the case of uniformly lower loss level, has a gradually decreasing length. If C is the cost per kilowatt of new installed capacity, and r the yearly rate of fixed charges (in decimal), the money saving effected because of such deferment on the $(n+1)$th generating unit, *at the time this unit is required in the reference plan* B, is

$$(S_n{}'')=CWD_n{}''r \tag{14}$$

To determine the worth of this saving at time t_0, when the power-loss reduction is assumed to obtain, a factor of "present value" has to be applied to $(S_n{}'')$. This factor is $1/(1+i)^{t_n}$, where i is the interest rate (in decimal) and t_n is the time of installation of the $(n+1)$th unit in the reference plan, counted in years from t_0. Therefore, the "present value" of the saving on the $(n+1)$th unit is

$$S_n{}''=\frac{CWD_n{}''r}{(1+i)^{t_n}} \tag{15}$$

The total economic benefit produced by the individual loss reduction will be the summation of the "present values" applicable to each of the u generating units necessary to reach the expected ultimate capacity of the system. Consequently, this total benefit is given by the expression:

$$S_0{}''+S_1{}''+\ldots+S_u{}''=\sum_{n=0}^{n=u-1}\frac{CWD_n{}''r}{(1+i)^{t_n}}$$

The money saving per kilowatt of peak power-loss reduction, which can be considered as the cost of such losses, is obtained by dividing the foregoing summation by the loss reduction $(1-k)G_0$ and is

$$s=\frac{1}{(1-k)G_0}\sum_{n=0}^{n=u-1}\frac{CWD_n{}''r}{(1+i)^{t_n}} \tag{16}$$

If the value derived from equations 13 or 13′ is substituted for $D_n{}''$, the foregoing expression can be written

$$s=\frac{1}{(1-k)p}\sum_{n=0}^{n=u-1}\frac{Cr}{(1+i)^{t_n}\log h_m}\log\frac{p+n}{kp+n} \tag{17}$$

or, in simplified form:

$$s=\sum_{n=0}^{n=u-1}\frac{Cr}{(1+i)^{t_n}(h_m-1)(kp+n)} \tag{17′}$$

The interval t_n to elapse for the installation of each unit, could be derived from

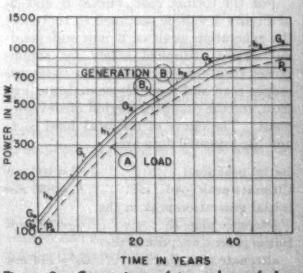

Figure 3. Comparison of two plans of development of an electric system, with different percentage of peak power losses

equation 2 but is more readily and with sufficient approximation determined from the graphic of trend curve B. This same graphic also will indicate the value of the growth factor h_m applicable to the various units.

It appears that the worth s is influenced both by the percentage of loss reduction, which is a function of k and by the size of generating unit used for calculations, from which p is determined. However, it will be found that, with data corresponding to practical possibilities, the influence of variation of these two factors is very slight

Table IV

Generating Units No.	n	Time of Installation t_n (Years)	Factor of Growth h_m	a: 1 / log h_m	b: $\frac{1}{(1+i)^{t_n}}$ i=0.06	b: $\frac{1}{(1+i)^{t_n}}$ i=0.08	c: log $\frac{p+n}{kp+n}$	d: abc i=0.06	e: abc i=0.08
1	0	0	1.05	47.2	1	1	0.02228	1.052	1.052
2	1	3.7	1.05	47.2	0.805	0.750	0.01848	0.702	0.654
3	2	6.9	1.05	47.2	0.680	0.580	0.01580	0.507	0.433
4	3	9.7	1.05	47.2	0.565	0.465	0.01379	0.368	0.303
5	4	12.1	1.04	58.7	0.490	0.390	0.01223	0.352	0.280
6	5	14.8	1.04	58.7	0.420	0.317	0.01100	0.271	0.204
7	6	17.3	1.04	58.7	0.363	0.260	0.00998	0.213	0.153
8	7	19.5	1.04	58.7	0.318	0.219	0.00914	0.171	0.118
9	8	21.5	1.04	58.7	0.285	0.187	0.00843	0.141	0.093
10	9	24.6	1.019	122.4	0.237	0.148	0.00783	0.227	0.142
11	10	26.5	1.019	122.4	0.190	0.110	0.00730	0.170	0.098
							Summation	4.174	3.530

and that normally the range of the consequent variation of s is well below ±5 per cent of its average.

As a rule, the simplified expression can be employed for calculations, and these may be accelerated further by the use of simple nomograms, as shown in the following paragraph.

Practical Application of the Method

Examples of application of the method will be given, both for the case of comparison of two alternate plans of system development with different level of peak power losses and for the case of evaluation of an individual reduction of peak power losses.

Example 1

For the former case, curves B and B_1 of Figure 3 will be assumed to represent the generation peak of a new independent system supplied solely by steam-power plants, respectively, in a basic reference plan and in an alternate lower-loss plan, for the complete period of development. The curve of the peak load is A, and the assumed data are:

Initial peak load ..... $P = 100$ mw
Ultimate peak load ..... $P_4 = 885$ mw
Initial generation peak in the reference plan B ..... $G_0 = 120$ mw
Initial generation peak in the alternate plan B_1 ..... $G_0' = 114$ mw
Factor of reduction of generation peak ..... $G_0'/G_0 = k = 0.95$
Factors of growth ..... $h_0 = 1.08$ $h_2 = 1.06$ $h_3 = 1.04$ $h_4 = 1.014$
Generation peaks in the reference plan B ..... $G_1 = 260$ mw $G_2 = 465$ mw $G_3 = 870$ mw $G_4 = 1{,}060$ mw
Ultimate loss reduction by alternate plan B_1 .... $(1-k)G_4 = 53$ mw
Capacity of generating units at ultimate development ..... $W = 80$ mw
Yearly rate of fixed charges: 13 per cent or, in decimal ..... $r = 0.13$

The application of equations 9 and 9′ up to the end of successive phases of development gives the results shown in Table I (see appendix for detail calculations). The error of the simplified equation 9′ is −5 per cent and, for a problem of this nature, can be considered of no consequence; furthermore, it is on the conservative side, so that the use of this equation will be admissible in most cases.

It is apparent that the latest stages of development, with low growth factors, have the greatest influence on the amount of savings, because of the longer deferment then obtaining for the installation of new units. With the data of the example, on the basis of equation 9′ and a uniform cost C of $100 per kilowatt of new capacity assumed, the estimated savings in the various stages would be as shown in Table II. Compared with the ultimate installation cost of $106,000,000, this represents an over-all economy of 17.6 per cent which, together with the energy savings, might justify the adoption of the development plan with lower loss level.

Example 2

An example of comparison and evaluation of the individual loss reduction in an existing system of the same type as the foregoing is shown in the lower part of Figure 4, where line B is the trend curve of the reference plan and line B_2 is the trend curve obtained by an individual loss reduction at time t_0. The data assumed for this example are:

Generation peak at time t_0 in the reference plan ..... $G_0 = 400$ mw
Loss reduction at time t_0, in the alternate plan ..... $g = 20$ mw
Generation peak at time t_0 in the alternate plan ..... $G_0'' = 380$ mw
Factor of reduction of generation peak at time t_0 ..... $G_0''/G_0 = k = 0.95$
Capacity of generating units .... $W = 80$ mw
Ratio of initial generation peak to unit capacity ..... $G_0/W = p = 5$
Rate of interest: 6 per cent or, in decimal ..... $i = 0.06$
Yearly rate of fixed charges: 13 per cent or, in decimal ..... $r = 0.13$
Factors of growth ..... $h_0 = 1.05$; $h_1 = 1.04$; $h_2 = 1.019$
Ultimate generation peak in the reference plan ..... $G_3 = 1{,}280$ mw
Total number of units of capacity W to be installed ..... $u = 11$

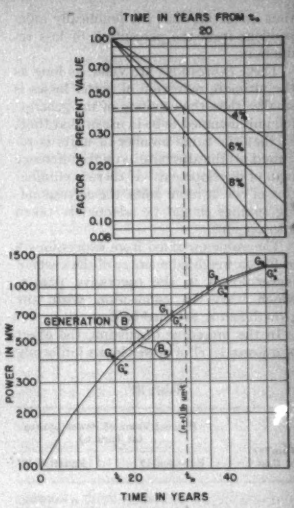

Figure 4. Comparison of two plans of development of an electric system, following an individual reduction of peak power losses

For the determination of factor $1+(1+i)^{t_n}$ appearing in equations 17 and 17′, the graphics of Figure 4 can be employed as follows: a vertical line is drawn from the point representing the $(n+1)$th unit on trend curve (B), to the straight radial line in the upper chart, labeled with the rate of interest to be used. The ordinate of the point of intersection, read on the scale at the left side of the chart, gives directly the value of $1/(1+i)^{t_n}$ applicable to that unit.

The partial values of power losses calculated by the two equations are given in Table III, which shows that the results of the exact formula 17 are practically identical to those of the simplified formula 17′. This latter will be used preferably, because it is of easier application, and calculations of its terms can be accelerated further by the use of nomogram Figure 5, which gives the value of factor $1/(k-1)(kp+n)$, as explained in the note on the figure. Detail calculations are given in the appendix.

If C is assumed to remain constant, the summation of the foregoing partial values gives $s = 2.17\ C$, but there is a considerable influence of the rate of interest upon this value. If the rate, instead of being six per cent as used in the preceding example, is eight per cent, the value of s is lowered to $1.83\ C$, a reduction of approximately sixteen per cent.

It may be observed that all values of peak power losses calculated are greater than the capital cost C of new generating capacity, contrary to assumptions frequently made.

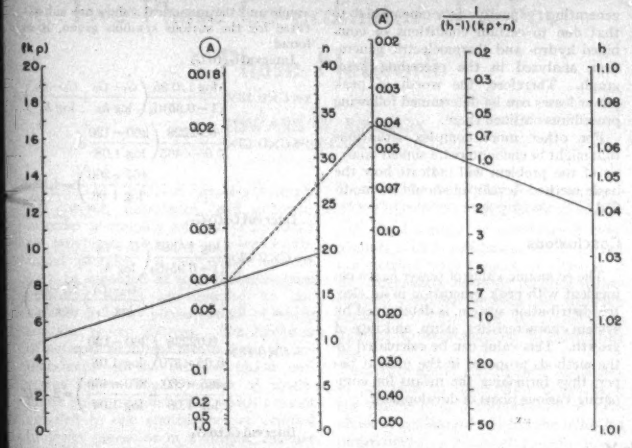

Figure 5. Nomogram for calculation of term $1/(h-1)(kp+n)$ in equation 17'

Given the quantities h, k, p, and n, draw a straight line from the value of kp on the scale so labeled to n on its own scale. Transfer the reading thus obtained on auxiliary scale A to auxiliary scale A', as shown by dotted line, and draw a straight line from this point to the point representing h on its own scale. The intersection of this line with the scale labeled $1/(h-1)(kp+n)$ gives the requested quantity

A comparison between the economic value of an individual reduction of peak power losses and that of the corresponding reduction of energy losses will be interesting. The 20-megawatt reduction of the example can be assumed to reduce the annual energy losses by 50,000,000 kilowatt-hours: if the cost of energy is three mils per kilowatt-hour, the consequent money saving will be $150,000 per year, which, capitalized up to the time of ultimate development on the basis of the same interest rate of six per cent used previously, has a present value of $2,100,000. On the other hand, if it is assumed that the capital cost of new generating capacity C is $100 per kilowatt, the present value of the savings due to the reduction of peak power losses by 20,000 kw, is $4,340,000, or slightly more than twice the value of energy losses. Such ratio is almost unaffected by the rate of interest.

Outline of Procedure for the Economic Evaluation of Power Losses in Systems of Other Types

Independent Hydroelectric Systems

When the sources of power of a system consist solely of hydroelectric plants, these necessarily will include large reservoirs to permit regulation of the total output at any time, in accordance with load requirements. Unregulated plants usually will have installed capacity adequate to utilize such high flow as economically convenient, while regulated plants will have enough capacity to take care of the total load at the time of the lowest output of the former. Whether such condition is coincident with the yearly peak load or not, it will be found that, generally, the regulated plants are called upon to provide part of the generation to cover this peak, in years of low flow.

In such a system, the needs of new capacity will involve periodical construction of entirely new projects and their transmission facilities, with a possible graduation in the number of units and transmission lines installed. The time when each new project and its eventual complementary additions shall be ready for service in the basic reference plan will be derived from a trend curve of the generation peak similar to B on Figures 3 and 4. The deferments obtainable in the construction of the various projects, by reduction of peak power losses, then are determined, either by formula 12 or by formulas 13 and 13', according to the proposed problem. On the basis of these deferments, the corresponding savings of fixed charges and their accrued or present value can be calculated, as required.

It should be noted that the capacity to be assigned to each hydroelectric plant is the net capacity available at the load centers, after deduction of transmission losses. The economy of the latter constitutes a separate problem from that of distribution losses.

Independent Systems with Combined Generation

In a system where thermoelectric and hydroelectric generation are combined, conditions may vary widely, in connection with the relative importance of the two sources of supply.

When thermoelectric plants are only for stand-by purpose, their capacity will not be affected appreciably, as a rule, by possible reduction of power losses. Therefore, the procedure for determining the worth of peak power losses will be the same as previously outlined for a purely hydroelectric system.

On the other hand, if the two sources of supply are of approximately equivalent importance, the plan of development will call for alternate construction of either type of plant, and the methods of evaluation will be a combination of those already discussed.

A situation which may be encountered is that of a system having part of its supply provided by hydroelectric plants of fixed firm capacity, with no possibility or convenience of expansion and its main supply provided by thermoelectric stations. In this case there will be an estimated firm availability of hydroelectric power at the time of the yearly peak load and a minimum availability at the time of low flow, whenever the two conditions do not coincide.

Trend curves of the load and total generation should be plotted for these two conditions, and then the corresponding values of the hydroelectric contribution should be deducted from total generation, to obtain the trend curve of thermoelectric generation alone. The condition requiring higher values for this latter, will be selected for the application of the method previously discussed.

The segments of the trend line of the peak generation thus obtained are not, theoretically, rectilinear, but they can be considered as such without appreciable error. The value of the growth factor h_m' applicable to a segment between time t_m and time t_{m+1} is given by the relation:

$$\log h_m' = \frac{1}{t_{m+1} - t_m} \log \frac{G_{m+1} - G_e}{G_m - G_e}$$

where G_m and G_{m+1} represent total generation and G_e the fixed value of firm hydroelectric generation.

In this case, since the hydroelectric portion of generation is not affected by eventual reduction of power losses, in order to simplify calculations, the factor k by which the ratio of reduction is measured, should be referred to thermoelectric generation alone. The trend curves of peak thermoelectric generation in alternate plans, having lower loss level or involving an individual loss reduction, then will be obtained from the analogous trend curve representing the basic reference plan, with the procedure previously explained.

If thermoelectric generation peak and peak load coincide, the method for economic evaluation of peak power losses is exactly the same as described in the examples. In the other alternative, however, that the two peaks do not coincide,

the following modifications are necessary:

(*a*). The power losses, to be deducted to obtain the trend curves of alternate plans, are only a fraction of the peak power losses. Namely, if q designates the ratio between the kilovolt-ampere values of the loads at the time of greatest thermoelectric generation and at the time of the yearly peak load, the ratio of the corresponding losses may be estimated to be very approximately q^2. For definite system characteristics, this ratio will be subject to minor variations over the whole period of development, so that it may be assumed to remain constant; consequently, if w and w_p are those two losses, it will be

$$w = q^2 w_p$$

(*b*). If peak power losses are reduced, so as to obtain a constant ratio of reduction of total peak generation, the ratio of reduction applicable to the case under consideration will not be constant. Its average value applicable to any segment of the trend curve will have to be calculated on the basis of power losses, and used in the formulas where it appears.

(*c*). After the worth s_1 of power losses has been determined by application of the proper equations, the value s valid for the corresponding peak power losses will be derived from the relation:

$$s = q^2 s_1$$

Since factor q is smaller than unity, it is evident that the worth of peak power losses may be reduced appreciably when there is no coincidence between yearly peak load and highest requirement of thermoelectric generation.

Interconnected Systems

Interconnected systems may belong to any of the types previously described, and the possibility of drawing power from interconnections will add a new element modifying the requirements of generating capacity within the system.

Power supply by interconnections may be divided broadly into two categories: firm and surplus (or secondary). The influence of each category upon system generating capacity is comparable to that due to certain conditions of combined hydro- and thermoelectric generation, analyzed in the preceding paragraph. Therefore, the worth of peak power losses can be determined following procedures outlined there.

For other more complex situations that might be encountered, a similar analysis of the problem will indicate how the basic method developed should be modified.

Conclusions

The economic value of power losses coincident with peak generation in an electric distribution system, is determined by system characteristics, setup, and rate of growth. This value can be calculated by the methods proposed in the present paper, thus furnishing the means for comparing various plans of development.

As in all problems of this nature, the mathematical solution is based on some simplified theoretical assumptions, from which actual conditions may more or less diverge. Such divergences can affect in a certain measure the absolute accuracy of the results, but, for the purpose of comparison, they will have, as a rule, negligible influence.

The worth of power losses is comparable to and in particular cases may be appreciably above that of the consequent energy losses.

Appendix. Calculations of Worth of Power Losses for the Illustrative Examples

Detail Calculations for Example 1

1. By equation 9:

$$s = Cr \frac{\log 1/k}{(1-k)G_n} \sum_{n=0}^{n=u-1} \frac{G_{n+1} - G_n}{\log h_n}$$

If the foregoing expression is written for the three intervals considered in the example and the numerical values are substituted for the various symbols given, it is found:

Interval G_0 to G_2

$$s = C \times 0.13 \times \frac{\log 1/0.95}{(1-0.95)G_2}\left(\frac{G_1 - G_0}{\log h_0} + \frac{G_2 - G_1}{\log h_1}\right)$$

$$= C \times 0.13 \times \frac{0.02228}{0.05 \times 465}\left(\frac{260-120}{\log 1.08} + \frac{465-260}{\log 1.06}\right) = 1.53C$$

Interval G_0 to G_3

$$s = C \times 0.13 \times \frac{\log 1/0.95}{(1-0.95)G_3}\left(\frac{G_1 - G_0}{\log h_0} + \frac{G_2 - G_1}{\log h_1} + \frac{G_3 - G_2}{\log h_2}\right)$$

$$= C \times 0.13 \times \frac{0.02228}{0.05 \times 870}\left(\frac{260-120}{\log 1.08} + \frac{465-260}{\log 1.06} + \frac{870-465}{\log 1.04}\right) = 2.40C$$

Interval G_0 to G_4

$$s = C \times 0.13 \times \frac{\log 1/0.95}{(1-0.95)G_4}\left(\frac{G_1 - G_0}{\log h_0} + \frac{G_2 - G_1}{\log h_1} + \frac{G_3 - G_2}{\log h_2} + \frac{G_4 - G_3}{\log h_3}\right)$$

$$= C \times 0.13 \times \frac{0.02228}{0.05 \times 1{,}060}\left(\frac{260-120}{\log 1.08} + \frac{465-260}{\log 1.06} + \frac{870-465}{\log 1.04} + \frac{1{,}060-870}{\log 1.014}\right) = 3.72C$$

2. By equation 9′:

$$s = \frac{Cr}{G_u} \sum_{n=0}^{n=u-1} \frac{G_{n+1} - G_n}{h_n - 1}$$

By analogous procedure as in the foregoing, it is found:

Interval G_0 to G_2

$$s = C \times \frac{0.13}{G_2}\left(\frac{G_1 - G_0}{h_0 - 1} + \frac{G_2 - G_1}{h_1 - 1}\right)$$

$$= C \times \frac{0.13}{465}\left(\frac{260-120}{1.08-1} + \frac{465-260}{1.06-1}\right) = 1.45C$$

Interval G_0 to G_3

$$s = C \times \frac{0.13}{G_3}\left(\frac{G_1 - G_0}{h_0 - 1} + \frac{G_2 - G_1}{h_1 - 1} + \frac{G_3 - G_2}{h_2 - 1}\right)$$

$$= C \times \frac{0.13}{870}\left(\frac{260-120}{1.08-1} + \frac{465-260}{1.06-1} + \frac{870-465}{1.04-1}\right) = 2.27C$$

Interval G_0 to G_4

$$s = C \times \frac{0.13}{G_4}\left(\frac{G_1 - G_0}{h_0 - 1} + \frac{G_2 - G_1}{h_1 - 1} + \frac{G_3 - G_2}{h_2 - 1} + \frac{G_4 - G_3}{h_3 - 1}\right)$$

$$= C \times \frac{0.13}{1{,}060}\left(\frac{260-120}{1.08-1} + \frac{465-260}{1.06-1} + \frac{870-465}{1.04-1} + \frac{1{,}060-870}{1.014-1}\right) = 3.53C$$

The total savings applicable to each of the three intervals, on the basis of a uniform

Table V

Generating Units No.	n	Time of Installation t_n (Years)	Factor of Growth h_m	a $\frac{1}{h_m - 1}$	b $\frac{1}{(1+i)^t_n}$ i=0.06	b i=0.08	c $\frac{1}{kp+n}$	d abc i=0.06	e i=0.08
1	0	0	1.05	.20	1	1	0.210	4.20	4.20
2	1	3.7	1.05	.20	0.805	0.750	0.174	2.80	2.61
3	2	6.9	1.05	.20	0.680	0.580	0.148	2.01	1.71
4	3	9.7	1.05	.20	0.565	0.465	0.129	1.46	1.20
5	4	12.1	1.04	.25	0.490	0.390	0.1145	1.40	1.11
6	5	14.8	1.04	.25	0.420	0.317	0.1025	1.075	0.81
7	6	17.3	1.04	.25	0.363	0.260	0.093	0.845	0.605
8	7	19.5	1.04	.25	0.318	0.219	0.085	0.67	0.46
9	8	21.5	1.04	.25	0.285	0.187	0.0785	0.56	0.365
10	9	24.6	1.019	52.7	0.237	0.148	0.0727	0.91	0.57
11	10	26.5	1.019	52.7	0.190	0.110	0.0678	0.68	0.39
							Summation	16.61	14.03

Two-Phase Co-ordinates of a Four-Phase Network

EDWARD W. KIMBARK
MEMBER AIEE

SUBSTITUTION of variables (voltage, current, impedance, and so forth) in order to simplify solution of problems on polyphase networks is a well-established practice. A polyphase network may be regarded as several single-phase networks which are coupled to one another in many places and all of which contain power sources. Simplification of network problems results from the replacement of the original phase networks by an equal number of single-phase substitute networks which are not coupled to one another or are coupled in fewer places or in a simpler manner than the phase networks, and which, preferably, have fewer power sources. In these substitute networks, the substitute currents and voltages exist.

Three-phase networks, because of their importance, have been given the most attention. The best-known and most widely used substitution is that of symmetrical components of a three-phase network, introduced by C. L. Fortescue[1] in 1918, and applied to many practical problems since that time.[2] The method of symmetrical components has the following useful properties:

1. The substitute networks (also called sequence networks) are independent of one another in all branches, including rotating machines, for which the three-phase network is balanced.

2. Certain unbalances, notably, short circuits, result in simple types of coupling between the sequence networks.

3. Normally only the positive-sequence network contains power sources.

A disadvantage of symmetrical components is that unbalances which are not symmetrical with respect to phase *a* of the three-phase network produce nonreciprocal coupling between the sequence networks. This type of coupling is difficult to represent on a calculating board.

Another useful substitution applicable to problems in three-phase networks is one called α, β, 0 components[3] or two-phase co-ordinates.[4] It has the following properties:

1. The substitute networks are independent of one another in all branches for which the three-phase network is balanced, except in rotating machines. They are independent also in rotating machines if the positive- and negative-sequence impedances of the machines are equal or are assumed to be equal.

2. Furthermore, one of the networks is independent of the other two for all unbalances which are symmetrical with respect to phase *a*, such, for example, as open-delta or *T*-connected transformers and simple short circuits.

3. There are power sources in two of the substitute networks. Their voltages are normally equal in magnitude and 90 degrees apart in phase.

4. All types of unbalance, except in rotating machines, in the three-phase network give reciprocal coupling between substitute networks.

Fortescue[1] stated the general principles of analysis of polyphase networks of any number of phases by means of symmetrical components. The properties of *n*-phase symmetrical components are similar to those stated previously for three phases. A recent paper by Boyajian[5] treats the analysis of four-phase networks by means of symmetrical components and gives equivalent circuits for several types of unbalance, including single-phase loads connected from line to neutral and from line to line.

The present paper describes a new method of analysis of four-phase networks, for which the name *two-phase co-ordinates* is proposed. In this method a four-phase five-wire network is regarded as two single-phase three-wire networks with common neutral. Each of these two networks is then replaced by its symmetrical-component networks, as described in the following. The properties of the resulting substitute variables are much like those listed previously for

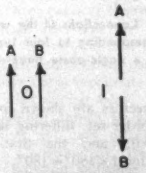

Figure 1. Symmetrical sets of current or voltage vectors of a single-phase three-wire system

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cost C of $100 per kilowatt of new capacity, are determined as follows:

Interval G_0-G_2 Total loss reduction:

$(1-k)G_2=0.05\times465=23.25$ megawatts

Total savings:

$1.45\times100\times23,250=\$3,371,250$

Interval G_2-G_3 Total loss reduction:

$(1-k)G_3=0.05\times870=43.5$ megawatts

Total savings:

$2.27\times100\times43,500=\$9,874,500$

Interval G_3-G_4 Total loss reduction:

$(1-k)G_4=0.05\times1,060=53.0$ megawatts

Total savings:

$3.53\times100\times53,000=\$18,709,000$

The partial savings in the various stages of development are obtained as difference of the totals given.

Detail Calculations for Example 2

1. By equation 17:

$$s=\frac{Cr}{(1-k)p}\sum_{n=0}^{n=u-1}\frac{1}{(1+i)^{t_n}\log h_m}\log\frac{p+n}{kp+n}$$

The values of the component factors of the terms under summation sign, for each of the 11 units to be installed, are given in Table IV, taking into account that $k=0.95$ and $p=5$. The product of the factors of columns *a*, *b*, and *c* gives the individual summation terms. The time of installation of each unit, as well as the factor of present value, were derived from the graphics of Figure 4, taking into account that time t_n is measured assuming t_0 as origin. The worth of power losses applicable to each generating unit, given in Table III, is derived multiplying the individual values of column *d* by the factor:

$$\frac{r}{(1-k)p}C=\frac{0.13}{(1-0.95)5}C=0.52C$$

and is valid for the rate of interest six per cent. The total worth for the rate of interest eight per cent also mentioned in the example is obtained as product of the summation of column *e* by the same factor $0.52\,C$.

2. By equation 17′

$$S=Cr\sum_{n=0}^{n=u-1}\frac{1}{(1+i)^{t_n}(h_m-1)(kp+n)}$$

By similar procedure as previously explained, Table V can be established.

The worth of power losses applicable to each generating unit, given in Table III, is derived multiplying the individual values of column *d* by the factor:

$$Cr=0.13C$$

and is valid for the rate of interest six per cent. There is practical coincidence of the values of power losses obtained by equations 17 and 17′.

two-phase co-ordinates of a three-phase network.

Symmetrical Components of a Single-Phase Three-Wire Network

Currents and Voltages

A symmetrical n-phase system has n voltages equal in magnitude and spaced $360°/n$ apart in phase. If n equals 2, the result is not a two-phase system, in the usual sense of that term, but rather a single-phase three-wire system. The characteristic angle is $360°/2=180°$. The two symmetrical sets of current or

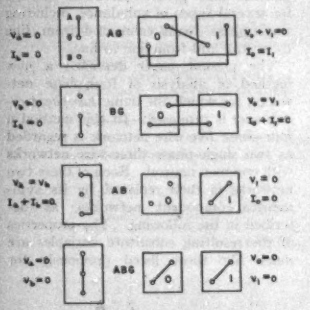

Figure 2. Connections of the sequence networks corresponding to four types of short circuit on a single-phase three-wire network

voltage vectors are shown in Figure 1: the zero-order set, differing in phase by $0\times180°=0$; and the first-order set, differing by $1\times180°=180°$. Zero-order currents are equal and in phase in the two outer wires, and return in the neutral wire or in the earth. They result from unbalanced line-to-neutral load or line-to-ground short circuits. First-order currents are equal and opposite in the two outer wires. They result from line-to-line loads or short circuits. The phase currents I_a and I_b in the outer conductors are given in terms of their symmetrical components I_0 and I_1 by the following equations:

$$I_a=I_0+I_1 \tag{1}$$

$$I_b=I_0-I_1 \tag{2}$$

The inverse equations are:

$$I_0=(I_a+I_b)/2 \tag{3}$$

$$I_1=(I_a-I_b)/2 \tag{4}$$

Similar equations hold for voltages.

Impedances

Consider a circuit element, such as a transformer or line, for which the two phases, each consisting of an outer conductor with neutral or ground return, having equal self impedances Z_s and mutual impedance Z_m. The phase voltages, in terms of the phase currents and impedances, are:

$$V_a=Z_sI_a+Z_mI_b \tag{5}$$

$$V_b=Z_mI_a+Z_sI_b \tag{6}$$

The symmetrical components of voltage are:

$$V_0=(V_a+V_b)/2 \\ =(Z_s+Z_m)(I_a+I_b)/2=Z_0I_0 \tag{7}$$

$$V_1=(V_a-V_b)/2 \\ =(Z_s-Z_m)(I_a-I_b)/2=Z_1I_1 \tag{8}$$

where $Z_0=Z_s+Z_m$ and $Z_1=Z_s-Z_m$. For circuits of the type described, the two substitute circuits are independent. That, of course, is the advantage of the substitution.

Short Circuits

There are four different types of short circuit on a single-phase three-wire circuit, as shown in Figure 2. The equivalent connections between substitute networks are also shown there.

Transformers

The zero-order equivalent circuits of several transformer connections are shown in Figure 3. The zero-order impedance of a winding is measured by applying single-phase voltage from the two outer terminals, joined together, to the neutral tap, and by taking the ratio of applied voltage to the current in half the winding. The first-order circuit is the same for all the connections shown; it is the ordinary equivalent circuit of a transformer.

Four-Phase Networks

Currents and Voltages

A four-phase network may be regarded as two single-phase three-wire networks, with the normal currents and voltages of one in quadrature with those of the other; and the substitutions described previously for such networks may be applied to each. The substitute currents (denoted by subscripts 4, 5, 6, 7) expressed in terms of phase currents (a, b, c, d) are then as follows:

$$I_4=(I_a+I_c)/2 \tag{9}$$

$$I_5=(I_a-I_c)/2 \tag{10}$$

$$I_6=(I_b+I_d)/2 \tag{11}$$

$$I_7=(I_b-I_d)/2 \tag{12}$$

The inverse equations are:

$$I_a=I_4+I_5 \tag{13}$$

$$I_c=I_4-I_5 \tag{14}$$

$$I_b=I_6+I_7 \tag{15}$$

$$I_d=I_6-I_7 \tag{16}$$

Similar equations hold for voltages. The computation required to go from phase quantities to two-phase co-ordinates and back is extremely simple.

Transformers

Usually a four-phase network is fed from two transformers, the center taps of which are joined. When the substitution of variables, described by equations 9 to 16, is used, the two substitute networks of each transformer are independent, just as they are for one transformer on a single-phase three-wire system. Furthermore, the two transformers are independent of each other. Therefore, the substitution is suitable even if the two transformers of a bank differ in impedance, ratio, or both. If the transformers are Scott-connected, two-phase co-ordinates may be used for circuits on the three-phase side.[4]

Short Circuits on a Four-Phase Network

There are 16 different types of short circuit on a four-phase network, including double short circuits. These are listed in Figure 4, together with the equivalent connections between networks of four-phase symmetrical components. In Figure 5 are shown the equivalent connections between substitute networks of

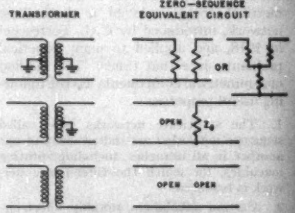

Figure 3. Zero-order equivalent circuits of single-phase transformers

two-phase co-ordinates. In many cases the connections are simpler in the latter system than in the former. However, it should be remembered that both networks 5 and 7 contain generated electromotive forces (normally in quadrature), whereas, in symmetrical components only the positive-sequence network (number 1) has them.

Modified Symmetrical Components

It is a familiar fact in symmetrical components of a three-phase system that the equations and the equivalent circuits of faults or other unbalances are simplest if the unbalance is symmetrical with respect to the reference phase (phase a). For example, a line-to-line short circuit is usually assumed to be on phases b and c for this reason. Otherwise, phase shifts would be required in the connections between sequence networks.

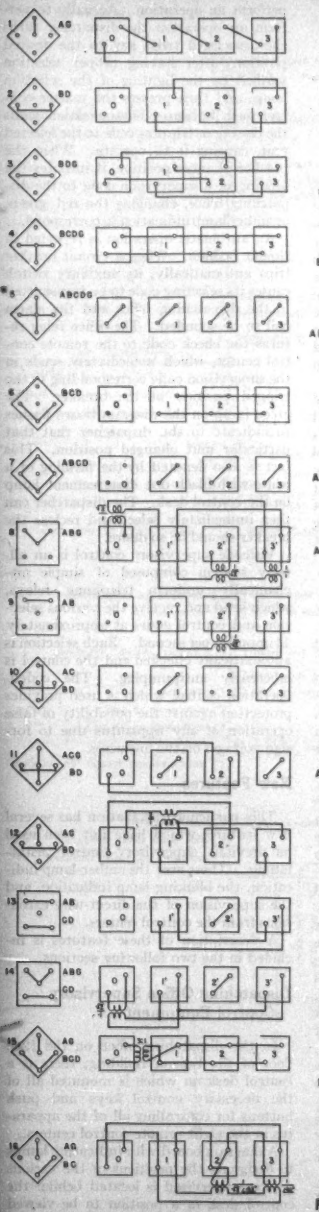

Figure 4. Connections of the sequence networks corresponding to 16 types of short circuit on a four-phase network

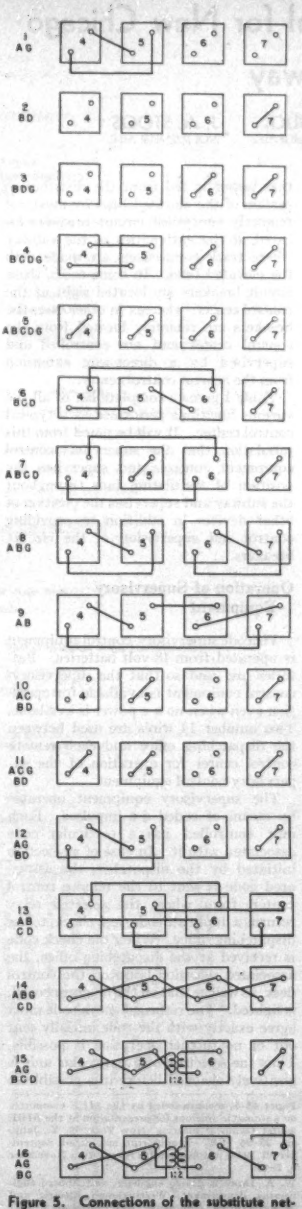

Figure 5. Connections of the substitute networks of two-phase co-ordinates corresponding to 16 types of short circuit on a four-phase network

In a four-phase system some faults are symmetrical with respect to phase a, but there are others, such as a short circuit between adjacent lines, which cannot be made so. Most such faults, however, are symmetrical about an axis midway between two phases. The following modified symmetrical components have the reference phase midway between phases a and b:

$$I_0 = (I_a + I_b + I_c + I_d)/4 \quad (17)$$

$$I_1' = (I_a/\underline{-45^\circ} + I_b/\underline{45^\circ} + I_c/\underline{135^\circ} + I_d/\underline{-135^\circ})/4 \quad (18)$$

$$I_2' = (I_a/\underline{-90^\circ} + I_b/\underline{90^\circ} + I_c/\underline{-90^\circ} + I_d/\underline{90^\circ})/4 \quad (19)$$

$$I_3' = (I_a/\underline{-135^\circ} + I_b/\underline{135^\circ} + I_c/\underline{45^\circ} + I_d/\underline{-45^\circ})/4 \quad (20)$$

The inverse equations are:

$$I_a = I_0 + I_1'/\underline{45^\circ} + I_2'/\underline{90^\circ} + I_3'/\underline{135^\circ} \quad (21)$$

$$I_b = I_0 + I_1'/\underline{-45^\circ} + I_2'/\underline{-90^\circ} + I_3'/\underline{-135^\circ} \quad (22)$$

$$I_c = I_0 + I_1'/\underline{-135^\circ} + I_2'/\underline{90^\circ} + I_3'/\underline{-45^\circ} \quad (23)$$

$$I_d = I_0 + I_1'/\underline{135^\circ} + I_2'/\underline{-90^\circ} + I_3'/\underline{45^\circ} \quad (24)$$

The modified symmetrical components are used in those parts of Figure 4 where the four-phase networks are indicated by squares with vertical and horizontal sides; regular symmetrical components are used where the networks are indicated by squares with sloping sides.

The unbalance shown in part 16 of Figure 4 does not have either type of symmetry. Consequently, the connection made between sequence networks for representing this unbalance requires transformers of complex ratio. When two-phase co-ordinates are used, however, none of the connections between substitute networks require such transformers.

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Supervisory Control for New Chicago Subway

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THE FIRST SECTION of the long-planned Chicago subway was opened to the public October 17, 1943. The section of subway which now is in daily operation extends along State Street and is 4.9 miles in length. This is but the first step in a program which ultimately may comprise as much as 50 miles of subway in the city of Chicago.

The necesssity of having the complete electric system under the control of a single operator resulted in the application of supervisory-control equipment. The supervisory-control dispatching-office equipment is located in the Chicago Rapid Transit Company office on the 12th floor of the Edison Building in downtown Chicago. Remote-station supervisory-control equipment is located at eight control centers in the subway. Figure 1 shows the location of the dispatching office with respect to the eight control centers. The Visicode type of supervisory-control equipment which was applied operates over a single pair of wires between the dispatching office and each of the remote control centers. There is also a pair of spare line wires for the control centers located north of the dispatcher's office and another pair for the centers south of the dispatcher's office. At each control center there is a toggle switch which is used to connect that center to the normal or the spare line.

The electric distribution system for the subway is shown in Figure 2. It will be noted from this figure that traction power is fed directly to the subway from three Commonwealth-Edison Company substations, namely, South State, East Lake, and Sedgwick, and in addition power is fed from the distribution system of the elevated lines by means of remotely controlled circuit breakers located at the extremities of the subway where track connections are made with the elevated lines. In some cases, these circuit breakers are located right at the control center, whereas in other cases the breakers are remotely located from the control center and are controlled and supervised by a direct-wire extension from the nearest control center.

Table I gives a complete list of all the various functions performed at a typical control center. It will be noted from this tabulation that the supervisory-control equipment controls and supervises the position of ventilating fans throughout the subway and supervises the position of other devices in addition to providing control and supervision of the circuit breakers.

Table I. Operations Performed by the Supervisory Control Equipment at a Typical Control Center

Supervise low battery voltage, battery ground, and line wire ground.
Control and supervise four circuit breakers in the control center.
Control and supervise station fans, low-speed forward, high-speed forward, and high-speed reverse.
Control and supervise five reclosing circuit breakers at a Commonwealth Edison Company substation.
Supervise normal- and emergency-service feeder voltage at each of two a-c switchboard rooms.
Supervise high-water and motor-overload trip at each of two pump rooms.
Control and supervise tunnel-fan high speed and tunnel-fan low speed or ventilating-louvre positions.
The supervisory control equipment provides space and wiring for the addition of seven future functions.

Operation of Supervisory Equipment

Visicode supervisory-control equipment is operated from 48-volt batteries. Batteries are used so that the supervisory-control equipment is available for operation even when no a-c power is available. Two number 14 wires are used between the dispatching office and each remote control center for operation of the supervisory-control equipment.

The supervisory equipment operates by means of coded d-c impulses. Each unit controlled has a particular code associated with it. In case of a selection initiated by the dispatcher, the associated code is sent to the remote control center, from where the selected relay returns a duplicate code, as a check, to the dispatching office. When the check code is received at the dispatching office, the associated selection lamp on the control desk, as well as that on the diagram board, is lighted. The returned check code must agree exactly with the code initially sent out or no further operation is possible. Thus the selection of a particular unit is positively checked before it is possible to perform an operation. Actually to perform an operation the dispatcher turns the associated twist key to the desired position, after having proper selection verified by the lighting of the selection lamp, and then presses the master control push button. This operation sends the closing or tripping code to the selected unit, causing it to operate. When the breaker changes position, it initiates the sending of a supervision code to the dispatching office, changing the red, green, or amber lamp indication to correspond.

An automatic operation is reported in similar fashion. When a circuit breaker trips automatically, its auxiliary switch causes its selecting code to be transmitted to the dispatching office and the alarm bell to be sounded. The office relay returns the check code to the remote control center, which immediately sends in the supervision code corresponding to the tripped position of the breaker. The green lamp on the diagram board flashes to indicate to the dispatcher that that particular unit changed position. This fact is also denoted by the flashing of a white-with-black-dot disagreement lamp on the control desk. The dispatcher can then immediately select and reclose the breaker should he so desire.

Visicode supervisory control is an all-relay system composed of simple mechanically uniform telephone relays, which send and receive the various selection and control codes at approximately 14 impulses per second. Each selection is automatically checked and the control is inherently antipumping. The coded-operation control which is used provides protection against the possibility of false operation of any apparatus due to foreign voltages on the line wires.

New Features

This particular installation has several new features which have not been used on previous supervisory-control installations. These are: the amber-lamp indication, the blinking-lamp indication, and the supervision of the direct-wire extensions from the control centers.

A description of these features is included in the two following sections.

Dispatching Office Supervisory Control Equipment

In the dispatching office on the 12th floor of the Edison Building, there is a control desk on which is mounted all of the necessary control keys and push buttons for controlling all of the apparatus in the eight remote control centers.

A diagram board with indicating lamps to designate the positions of the various devices supervised is located behind the control desk in a position to be viewed readily by the dispatcher. Figure 3 shows the control desk and the diagram board for the State Street subway.

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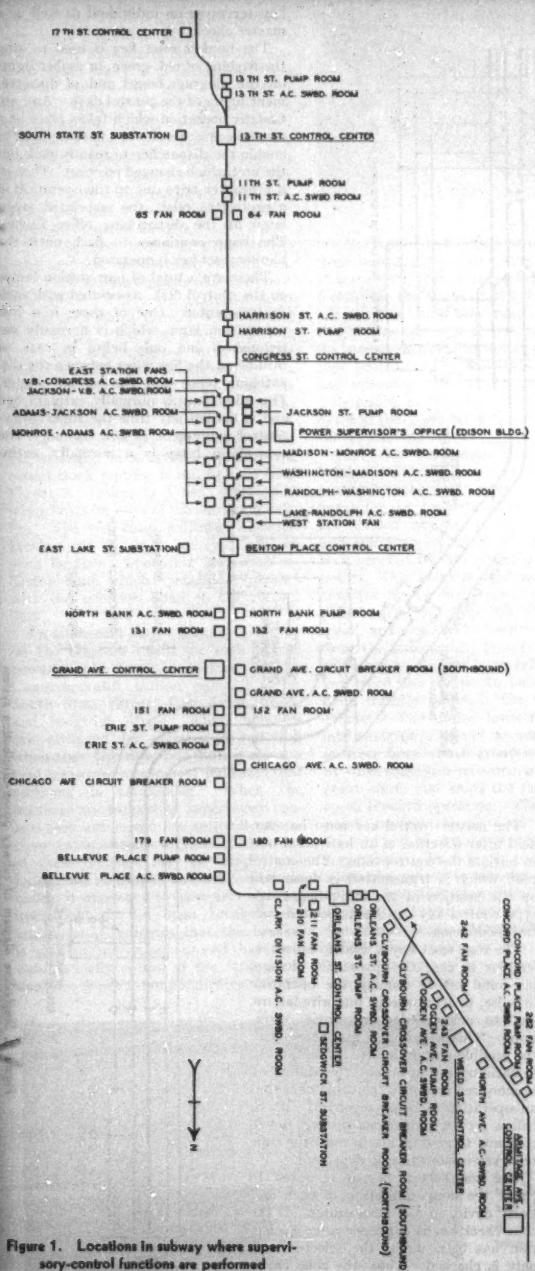

17 TH ST. CONTROL CENTER
13 TH ST. PUMP ROOM
13 TH ST. A.C. SWBD. ROOM
SOUTH STATE ST. SUBSTATION
13 TH ST. CONTROL CENTER
11 TH ST. PUMP ROOM
11 TH ST. A.C. SWBD. ROOM
65 FAN ROOM
64 FAN ROOM
HARRISON ST. A.C. SWBD. ROOM
HARRISON ST. PUMP ROOM
CONGRESS ST. CONTROL CENTER
EAST STATION FANS
V.B.-CONGRESS A.C. SWBD. ROOM
JACKSON - V.B. A.C. SWBD. ROOM
ADAMS-JACKSON A.C. SWBD. ROOM
JACKSON ST. PUMP ROOM
MONROE-ADAMS A.C. SWBD. ROOM
POWER SUPERVISOR'S OFFICE (EDISON BLDG.)
MADISON - MONROE A.C. SWBD. ROOM
WASHINGTON - MADISON A.C. SWBD. ROOM
RANDOLPH - WASHINGTON A.C. SWBD. ROOM
LAKE-RANDOLPH A.C. SWBD. ROOM
WEST STATION FAN
EAST LAKE ST. SUBSTATION
BENTON PLACE CONTROL CENTER
NORTH BANK A.C. SWBD. ROOM
NORTH BANK PUMP ROOM
151 FAN ROOM
152 FAN ROOM
GRAND AVE. CONTROL CENTER
GRAND AVE. CIRCUIT BREAKER ROOM (SOUTHBOUND)
GRAND AVE. A.C. SWBD. ROOM
151 FAN ROOM
152 FAN ROOM
ERIE ST. PUMP ROOM
ERIE ST. A.C. SWBD. ROOM
CHICAGO AVE. A.C. SWBD. ROOM
CHICAGO AVE CIRCUIT BREAKER ROOM
179 FAN ROOM
180 FAN ROOM
BELLEVUE PLACE PUMP ROOM
BELLEVUE PLACE A.C. SWBD. ROOM
CLARK DIVISION A.C. SWBD. ROOM
211 FAN ROOM
210 FAN ROOM
ORLEANS ST. CONTROL CENTER
ORLEANS ST. PUMP ROOM
ORLEANS ST. A.C. SWBD. ROOM
MIDWICK ST. SUBSTATION
CLYBOURN CROSSOVER CIRCUIT BREAKER ROOM (SOUTHBOUND)
CLYBOURN CROSSOVER CIRCUIT BREAKER ROOM (NORTHBOUND)
OGDEN AVE. A.C. SWBD. ROOM
243 FAN ROOM
OGDEN AVE. PUMP ROOM
242 FAN ROOM
WEED ST. CONTROL CENTER
NORTH AVE. A.C. SWBD. ROOM
CONCORD PLACE A.C. SWBD. ROOM
CONCORD PLACE PUMP ROOM
238 FAN ROOM
ARMITAGE AVE. CONTROL CENTER
N

Figure 1. Locations in subway where supervisory-control functions are performed

The supervisory-control dispatching-office relay equipment is mounted in cases on the swinging panels of cabinets behind the diagram board.

The control desk is divided into eight sections corresponding to the eight control centers remotely controlled. There is a molded control-key plate or escutcheon for each piece of apparatus remotely controlled. There is space in each of the eight control-center sections of the control desk for mounting 24 of these control escutcheons. For the positions not now equipped there are molded blank plates. Wiring is installed in the control desk for all positions so an added function can be provided readily by replacing a blank plate with a control escutcheon.

Figure 4 shows a supervisory-control relay and a control-desk escutcheon. It will be noted that the escutcheon is equipped with a push-type selection key, a twist-type control key, a small white lamp, and a small white-with-black-dot lamp, as well as with two engraved name plates.

The small white lamp is the selection lamp. It is used to inform the dispatcher that the supervisory-control equipment has completed the selection of that particular unit and that the equipment is ready for further operation.

The white-with-black-dot lamp is the disagreement lamp which is used to indicate to the dispatcher that the setting of the individual twist-type control key disagrees with the position of the apparatus unit at the control center. For example, assume that the dispatcher has operated the individual twist-type control key to the "close" position and has closed a circuit breaker and this breaker opens due to the operation of protective devices at the remote control center. The disagreement lamp will then be lighted in addition to the green supervisory indicating lamp on the diagram board to inform the dispatcher that the particular unit has undergone a change and that the setting of the control key does not agree with the lamp indication.

The twist-type control key affords the dispatcher the means for selecting a "trip" or "close" operation. The setting of this key determines what operation is to be performed.

The nonlocking push-type selection key enables the dispatcher to set the supervisory-control equipment into operation to select a definite apparatus unit. Thus the dispatcher may cause the supervisory-control equipment to select any individual unit at the remote control center.

In addition to the individual control escutcheons just described, the control desk is equipped with four nonlocking push-type master control keys for each control center, designated as follows:

Master control key.
Zone reset key.
Zone check key.
Blinker reset key.

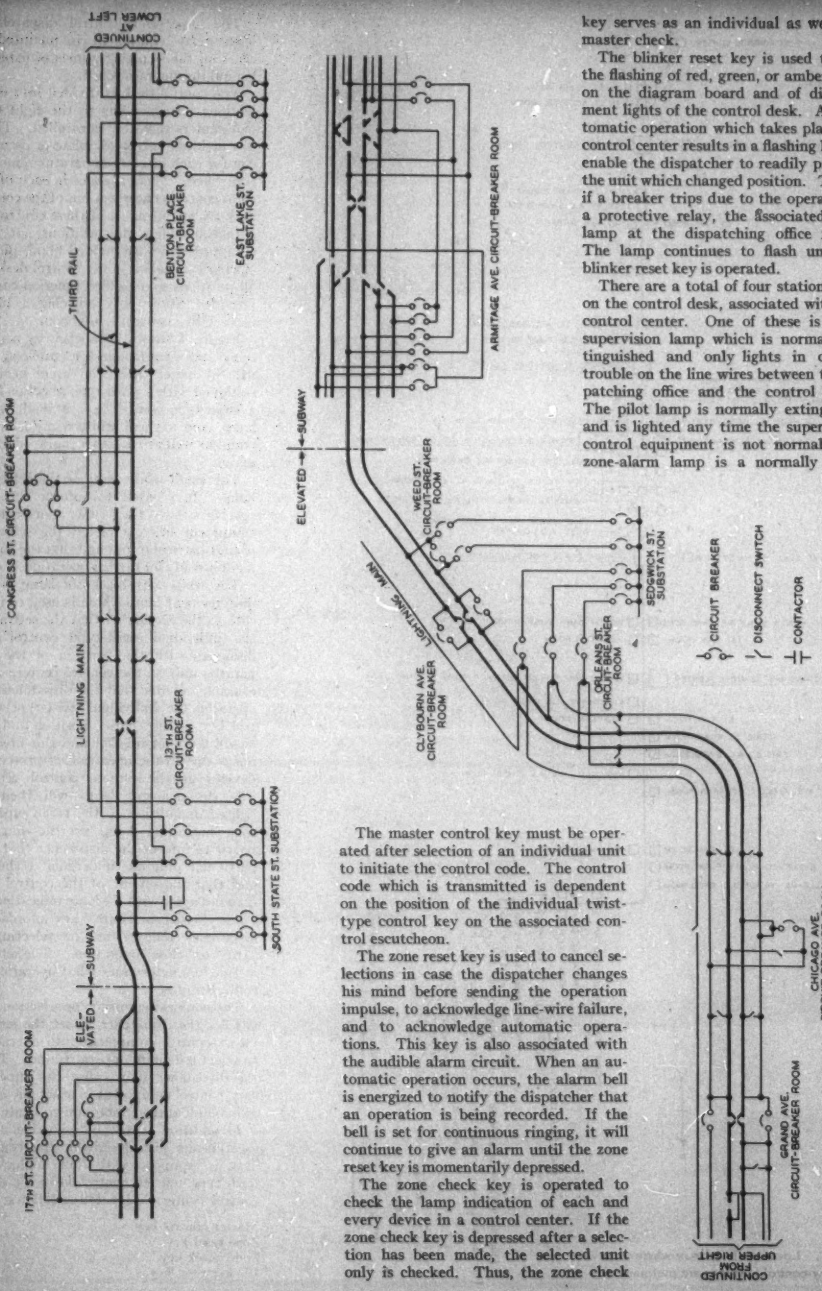


Figure 2. Single-line diagram of subway power-distribution system

key serves as an individual as well as a master check.

The blinker reset key is used to stop the flashing of red, green, or amber lights on the diagram board and of disagreement lights of the control desk. Any automatic operation which takes place at a control center results in a flashing light to enable the dispatcher to readily pick out the unit which changed position. That is, if a breaker trips due to the operation of a protective relay, the associated green lamp at the dispatching office flashes. The lamp continues to flash until the blinker reset key is operated.

There are a total of four station lamps on the control desk, associated with each control center. One of these is a line supervision lamp which is normally extinguished and only lights in case of trouble on the line wires between the dispatching office and the control center. The pilot lamp is normally extinguished and is lighted any time the supervisory-control equipment is not normal. The zone-alarm lamp is a normally extin-

The master control key must be operated after selection of an individual unit to initiate the control code. The control code which is transmitted is dependent on the position of the individual twist-type control key on the associated control escutcheon.

The zone reset key is used to cancel selections in case the dispatcher changes his mind before sending the operation impulse, to acknowledge line-wire failure, and to acknowledge automatic operations. This key is also associated with the audible alarm circuit. When an automatic operation occurs, the alarm bell is energized to notify the dispatcher that an operation is being recorded. If the bell is set for continuous ringing, it will continue to give an alarm until the zone reset key is momentarily depressed.

The zone check key is operated to check the lamp indication of each and every device in a control center. If the zone check key is depressed after a selection has been made, the selected unit only is checked. Thus, the zone check

guished lamp which is lighted whenever an automatic operation takes place. Each zone has a zone-alarm lamp on the diagram board which is in parallel with the one on the control desk. The fourth common lamp is used to indicate low control-center battery voltage, battery ground, or line-wire ground. This is a normally extinguished lamp which is lighted only to indicate trouble. The control desk is also equipped with jacks which are used to insert testing instruments into the line circuits.

The diagram board is divided into eight sections, one for each control center. Each section consists of four removable panels. There are dustproof doors on the rear which provide access to the panel wiring. The panels are finished in gray and are equipped with Vinylite plastic mimic bus of various colors. The lamps on the diagram board may be operated from an a-c supply or from the 48-volt battery.

The circuit-breaker indicating lamps are arranged in a layout depicting the actual track routing as can be seen from Figure 3. There is a red, green, and white lamp for each of the subway breakers. The red lamp indicates a closed breaker and the green lamp indicates an open breaker. The white lamp is a selection lamp which operates in parallel with the selection lamp on the control desk.

An additional amber lamp is furnished on the diagram board for each of the power-supply breakers located in the Commonwealth Edison substations at South State Street, East Lake Street, and Sedgwick Street. These breakers are arranged for automatic reclosing when they trip due to a fault if the d-c load-measuring equipment indicates that reclosing is permissible. When the breakers are tripped by supervisory control they are locked out and will not reclose automatically. The fact that one of these breakers may be tripped and locked out or tripped and not locked out makes it necessary to have two separate indications for an open breaker. An amber lamp indicates that the breaker is open but not locked out and that it will automatically reclose if the fault is removed. A green lamp indicates that the breaker is open and locked out. If one of these breakers trips due to the operation of protective devices an amber-lamp indication is the result at the dispatching office. The dispatcher may then lock this breaker out if he desires by selecting the point, setting the associated twist-type control key in the "trip" position, and operating the master control key. This results in the breaker being locked out and the green lamp being lighted at the dispatching office.

Just below the sections containing the breaker indicating lamps are the sections containing the red, green, and white lamps for the ventilating fans. The fans are divided into two types, tunnel fans and station fans. Each tunnel fan can be controlled by two supervisory control points. One point is used to start and stop the fan on high speed. The other point starts and stops the fan on low speed, and can also be used to open and close the independent louvres. The supervisory equipment is transferred from low speed fan control to louvre control by a transfer switch in the fan-control cabinet. The station fans are divided into two groups, one of six and the other of seven fans. Each group is controlled by three supervisory-control points. One point starts and stops the fans on low-speed forward operation. The other two points control the fans on high-speed forward and high-speed reverse operation respectively. Each fan is equipped with a transfer switch to transfer the control of that individual fan from supervisory to local push-button control. For each fan group, there is a lamp on the diagram board which indicates whether all the fans in that group have responded to the control operation. In all cases, a red lamp indicates that the fan is running, a green lamp indicates that the fan is stopped, and the white lamp is a selection lamp paralleling the selection lamp on the control-desk escutcheon.

Figure 4a (left). Typical supervisory-control relay

Figure 4b (right). Typical dispatcher's control and supervision escutcheon

The lamp indications for subway-pump alarms and the indications of a-c service are located on the lower sections of the diagram board. There is no remote control associated with these indications and hence there is no control escutcheon on the control desk associated with these indications. Only a red and a green lamp are used for these indications, no white selection lamp being required since no control of these units is provided from the control desk.

Control-Center Supervisory-Control Equipment

The control-center supervisory equipment is mounted on the swinging panels of cabinets suitable for mounting against the wall. On one swinging panel the supervisory-control relays are mounted in four cases. Relay equipment is provided for all of the present functions performed and there is space and wiring available to provide additional functions which it may be desirable to perform by the supervisory-control equipment in the future. The interposing relays which are under the control of the supervisory relays and which operate into the control circuits of the breakers located in the control-center room are mounted on the other swinging panel. Figure 5 shows the 13th Street control center with the supervisory-control panels in the background.

The interposing relays for the control of the units which are located at some distance from the control center and which are controlled by a direct-wire extension are located with the units controlled. These interposing relays are under control of the supervisory relays over wires extending between the supervisory-control relay equipment and the interposing-relay location.

Relays are provided in the supervisory-

Figure 3. Supervisory-control desk and diagram board in Edison Building power dispatcher's office

Figure 5. View of 13th Street control center showing rear view of circuit-breaker panels with supervisory-control panels in the background

control relay cases to provide an indication of low supervisory-control battery voltage. These relays operate at 45 volts so as to give an indication to the dispatcher before the battery voltage gets too low for operation of the supervisory equipment. The voltage-indication relays automatically restore when the voltage is raised to normal.

Grounds are detected on the control-center supervisory battery, the supervisory-control line wires between the dispatching office and the control center, and on all of the wires used for direct-wire extension from the control-center location by means of a Rectox ground detector. The Rectox ground detector is a full-wave rectifier unit, so connected as to cause a relay to operate when a ground occurs, resulting in an indication being transmitted to the dispatching office.

Table II

	Red Lamp	Green Lamp
Breaker closed by supervisory control	On	Off
Breaker opened by supervisory control	Off	On
Breaker in open position due to automatic tripping	Off	Flashing
Breaker closed locally	Flashing	Off

Table III

	Red Lamp	Green Lamp
Unit closed by supervisory control	On	Off
Unit opened by supervisory control	Off	On
Unit in open position due to automatic opening	Off	Flashing
Unit closed locally	Flashing	Off
Control and supervision wire broken	Flashing	Flashing

Detailed Description of Different Types of Control and Supervision

The fact that all of the equipment controlled and supervised is not located in the control center itself made it necessary to employ several different types of circuits for controlling and supervising the apparatus units involved. There are essentially four different circuit arrangements used, as will be described under the following subheadings.

A. Control and Supervision of Units Located in Control Center

For the control of units located right in the control center, there are two interposing relays on the control center panel for performing the "trip" and "close" operations. For all of these units, a single *a* auxiliary switch is used to obtain the red- and green-lamp indications at the dispatching office.

There are only two supervision codes associated with these units, a "trip" code of three impulses and a "close" code of five impulses.

Table II gives the lamp indications which are obtained at the dispatching office for manual and automatic operations on these units.

B. Single-Wire Extension Control and Supervision

The control of all fans and breakers not located right at the control center, with the exception of the automatic-reclosing Commonwealth Edison Company breakers, is arranged so that control and supervision is obtained over a single wire between the control center and the remote unit.

Figure 6 shows the elements of this direct-wire extension between the control center and the location of the remote unit. It will be noted from Figure 6 that an *a* and a *b* auxiliary switch are used for supervision purposes. The *a* auxiliary switch is connected to the negative side of the supervisory-control battery and the *b* auxiliary switch is connected to the positive side of the supervisory-control battery. The other sides of the *a* and *b* auxiliary switches connect to the coils of the "trip" and "close" interposing relays with the other side of the two interposing relays being connected to the single wire which extends to the control center. The two interposing relays which performed the control functions are energized by causing the proper polarity to be placed on the single control and supervision wire at the control center

The coils of the relays designated as *A* and *B* in Figure 6 are both connected to the single control and supervision wire at

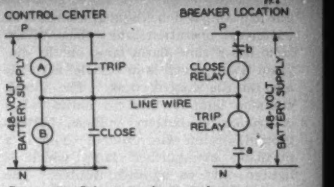


Figure 6. Schematic diagram showing essentials of single-wire control scheme

the control center. The resistance of this circuit is of such magnitude that approximately 20 milliamperes of current passes over the single control and supervision wire for supervision purposes. This current passes through the interposing-relay coil, but is only approximately 15 per cent of the current required for operation of the interposing relay. Thus the interposing relay does not operate until direct supervisory battery potential is placed on the control and supervision wire at the control center.

Either relay *A* or relay *B* will normally be energized at the control center due to either the *a* or the *b* switch of the breaker being closed. However, if the single control and supervision wire should become open, relays *A* and *B* will be energized in series. This fact makes it possible to supervise both positions of the remote breaker and also to supervise the continuity of the single control and supervision wire with relays *A* and *B*.

Table IV

	Red Lamp	Green Lamp
Unit in open position due to automatic opening	Off	Flashing
Unit closed locally	Flashing	Off
Supervision wire broken	Flashing	Flashing

Table V

	Red Lamp	Green Lamp	Amber Lamp
Breaker closed by supervisory control	On	Off	Off
Breaker opened by supervisory control	Off	On	Off
Breaker in open position due to automatic tripping	Off	Off	Flashing
Breaker locked out by supervisory control after automatic tripping	Off	On	Off
Breaker locked out by emergency alarm	Off	Flashing	Off
Breaker reclosed automatically	Flashing	Off	Off
Either or both control wires open	Flashing	Flashing	Off

Figure 7. View of typical pump room

The supervisory cabinet is the middle cabinet on the wall

There are three supervision codes associated with these units, a "trip" code of three impulses, a "close" code of five impulses, and a code of four impulses to indicate loss of the single-wire control and supervision circuit.

Table III gives the lamp indications which are obtained at the dispatching office on manual and automatic operations on these units.

C. Single-Wire-Extension Supervision

The supervision of a-c service voltage is arranged to operate over a single wire extending from the unit supervised to the control center. These units are arranged exactly as the single-wire control and supervision described in section B except that the interposing relays are omitted.

There are three supervision codes just as given in section B.

Table IV gives the lamp indications which are obtained at the dispatching office on automatic operations on these units.

Each of the pump rooms is supervised by a loop circuit which is opened in case of high water or motor overload trip. The lamp indications are the same as those listed above except that there is no indication for a broken wire. Figure 7 illustrates a typical pump room. The supervisory-control equipment is located in the center cabinet.

D. Two-Wire Extension Control and Supervision

Two wires are used between each of the automatic-reclosing Commonwealth Edison Company breakers and the control center for complete control and supervision of this breaker.

Figure 8 shows the elements of this direct-wire extension between the control center and the automatic-reclosing-breaker location. It will be noted from Figure 8 that one of the two wires is connected to the "trip" interposing relay. The other side of the "trip" interposing-relay coil connects to a make and a break contact of a toggle-type lockout relay. These contacts are designated as *MXC* and *MXT* on Figure 8.

If the breaker is tripped by operation of the supervisory-control "trip" interposing relay, the lockout relay is operated. This relay opens one of its contacts which is in series with the operating coil of the recloser, thus locking out the recloser. The supervisory-control "trip" interposing relay is operated either by having positive supervisory battery potential connected to the control wire by the supervisory-control equipment or by having this potential connected to the line wire by an emergency-alarm-relay contact located at the control center. The emergency-alarm system consists of pull boxes located at intervals along the track. These pull boxes are tied in with the supervisory-control relays at the control centers. When a pull box is operated, the breakers supplying that section of track are tripped and locked out.

If one of the automatic-reclosing breakers is tripped through the operation of protective equipment, the lockout relay is not operated, and hence the breaker will reclose as soon as the fault has cleared.

It will be noted from Figure 8 that the coils of relays *A* and *B* are both connected to the single trip wire at the control center and that relays *C* and *D* are both connected to the single close wire at the control center. The use of these four relays makes it possible to denote whether a breaker is closed, tripped but not locked out, or tripped and locked out, and also to supervise the continuity of the two control and supervision wires.

There are four supervision codes associated with the automatic-reclosing-breaker points—a "trip" code of three impulses if the breaker is tripped and locked out, a "trip" code of two impulses if the breaker is tripped but not locked out, a "close" code of five impulses, and code of four impulses to indicate trouble on either of the two control and supervision wires extending from the control center to the breaker.

Table V shows the lamp indications which are obtained at the dispatching office for manual and automatic operations of the automatic reclosing breakers.

Conclusion

The Visicode supervisory-control equipment used to control power for the State Street subway was designed to furnish all necessary information to the dispatcher in as small a space as feasible. This is of particular importance due to the future expansion of the subway system.

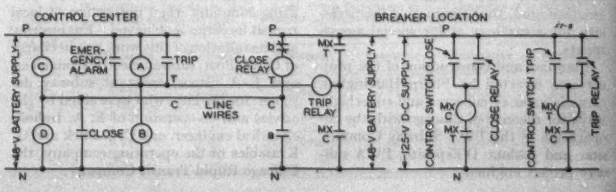
On supervisory-control systems built in the past, the change in position of a device has been indicated by the lighting of a disagreement lamp. This installation marked the advent of a new type of indication to indicate an automatic operation—the flashing of the red, green, or amber position-indicating lamp. The flashing-lamp signal has proved to be a definite improvement in locating a unit which has changed position, where a large number of units are involved.

The use of the single- and two-wire control schemes described has provided reliable operation with a minimum of conductors throughout the subway. The supervision of the wires involved in the direct-wire extensions from the control center is a unique feature.

Having the control of power circuits and ventilating means of the subway at the fingertips of one man provides fast and efficient operation.

The subway project was financed jointly by the city and the Public Works Administration of the federal government,

Figure 8. Schematic diagram showing essentials of control scheme for reclosing breakers



Graphical Method of Calculating Fault Currents on Rural Distribution Systems

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IN the application of fuses, oil circuit reclosers, or any other type of sectionalizing device on a distribution system, a considerable amount of time and effort is usually spent in calculating fault currents at various locations on the system. The purpose of this paper is to describe a graphical method of calculating the fault currents which simplifies the task of making the calculations. The advantages of the graphical method, over other methods commonly used to make fault-current calculations, are:

1. A visual picture is obtained of the possible fault currents at any location on the system.
2. There is less chance for error.
3. Considerable time and effort are saved in making the calculations.
4. A compact permanent record is obtained.
5. It provides an easy method of quickly calculating the fault currents on new extensions added to the system after the original fault-current study has been completed.

The graphical method outlined in this paper is an exact method of calculating the fault currents. The accuracy obtained depends upon the scale chosen for the calculation diagrams and the care taken by the person making the calculations.

Line-to-ground, line-to-line, and three-phase types of faults will be considered in the following discussion. The illustrations and examples used to describe the graphical method were designed for rural distribution lines of the multigrounded neutral type, having a nominal voltage of 7,200/12,470 volts. However, the fundamental principles of the graphical method can be applied to any distribution system.

Paper 45-8, recommended by the AIEE committee on protective devices for presentation at the AIEE winter technical meeting, New York, N. Y., January 22–26, 1945. Manuscript submitted April 24, 1944; made available for printing November 10, 1944.

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Description of Method

Fault-current calculations are made on current diagrams which are designed for a specific system voltage. A separate current diagram is used for line-to-ground, line-to-line, and three-phase faults. Typical current diagrams are shown in Figures 1 and 2, which are 7,200-volt diagrams for use on 7,200/12,470-volt multigrounded-neutral systems. The current diagrams in Figures 1 and 2 are exactly the same except for the line-mileage scales. The line-mileage scales in Figure 1 are for calculating line-to-ground faults and the line-mileage scales in Figure 2 are for calculating three-phase fault currents. A similar current diagram for calculating line-to-line fault currents would have line-mileage scales designed for line-to-line faults.

From the practical standpoint, the positive- and negative-sequence impedances of the power source may be assumed to be equal. If the further assumption is made that the equivalent spacing on two-phase lines is equal to the equivalent spacing on three-phase lines, then the line-to-line fault currents are equal to $\sqrt{3}/2$ times the three-phase fault currents. Therefore, for all practical purposes, line-to-line current diagrams are not absolutely necessary. Knowing the three-phase fault currents, the line-to-line fault currents can be calculated by a simple slide-rule operation.

The background of the current diagram in either Figure 1 or 2 is a rectangular co-ordinate system with resistance R in ohms along the horizontal axis and reactance X in ohms along the vertical axis. These resistance and reactance scales are for the total resistance and reactance values of the circuit from the power source to any point on the system where it is desired to know the fault current. The impedance of the circuit is

$$Z = \sqrt{R^2 + X^2}$$

which is in the form of the equation of a circle where Z is the radius and R and X are co-ordinates for any point on the circle. The quarter circles on the current diagrams are impedance circles, each circle representing a value of impedance for corresponding values of R and X on the resistance and reactance scales. Instead of indicating the value of impedance that each circle represents, the circles are calibrated in terms of current in amperes based on the system line to neutral voltage. The line-to-neutral voltage is used as the base voltage for line-to-ground, line-to-line, and three-phase current diagrams. Fault currents can be read on the circles at the intersection of the total resistance and total reactance values of the circuit from the power source to the fault location on the system. It should be remembered that in the case of voltage transformations in the circuit, the resistance and reactance values must be referred to the voltage base for which the current diagram is designed.

In the lower right-hand corner of each current diagram, there is a group of scales called "line-mileage scales," each scale representing a different copper equivalent conductor size. Each scale is calibrated in miles, starting from zero at the left end of the scale, which refers to the length of a section of distribution line. The slope and calibration of each scale is governed by the per mile resistance and reactance values of the distribution line. Therefore, to design a line-mileage scale for line-to-ground faults, it is necessary to know the per phase resistance and reactance of the line for line-to-ground faults and for the conductor used. It is necessary to know the resistance and reactance values of the system for line-to-line and for three-phase faults to design mileage scales for these respective types of faults.

To design a line-mileage scale, choose a convenient point on the diagram for the zero point of the scale. Using the same scale as the resistance and reactance scales on the current diagram, lay off a distance horizontally to the right, equal to the resistance of one mile of line. From the point just located, lay off a distance vertically upward equal to the reactance of one mile of line forming two legs of a right triangle, the hypotenuse of which is equal to the impedance of one mile of line on the bases of the scale used for the current diagram. Draw the hypotenuse and extend it upward to the right,

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the latter contributing $23,130,000 of the $57,400,000 total cost. The city's share, $34,270,000, was obtained from the traction fund, thus eliminating the necessity for a tax levy or for special assessments.

Planning and construction of the project was directed by Philip Harrington, commissioner of subways and superhighways for the city of Chicago with the cooperation of the PWA Subway Commission and Joshua D'Esposito, PWA subway project engineer.

The portion of the work covered by this paper was financed by the city alone. The city is to be reimbursed by the operating company when unification of local transit facilities is achieved. Engineering and installation of this work was in charge of C. W. Post, subway electrical engineer, and J. A. Stoos, assistant subway designer, for the city, who were aided by the advice and co-operation of E. A. Imhoff, electrical engineer, and C. J. Buck and G. Krambles of the operating company, the Chicago Rapid Transit Company.

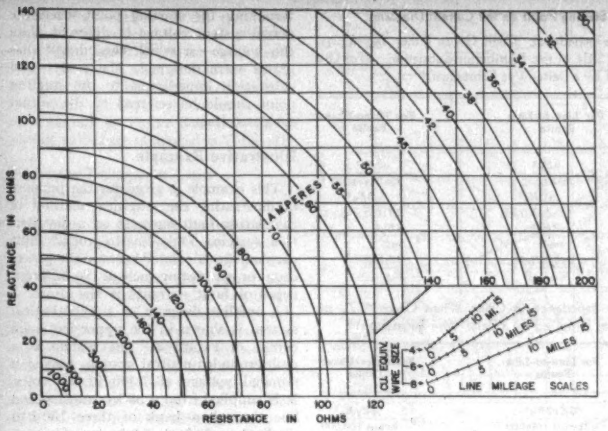

Figure 1. Typical 7,200-volt current diagram with line-mileage scales for calculating line-to-ground fault currents

forming the desired line-mileage scale. The scale can then be calibrated in miles by marking off distances equal to the length of the hypotenuse of the small impedance triangle. The use of the line-mileage scales in making fault current calculations will be explained farther on in this paper.

The line-mileage scales on the current diagrams shown in Figures 1 and 2 are for rural distribution lines constructed to the specifications of the Rural Electrification Administration. Values of resistance and reactance per mile for REA lines, which were used in designing the line-mileage scales, are given in Table I, which are average values for the various types of conductor used. The resistance and reactance of Copperweld, aluminum conductor steel reinforced, hard-drawn copper, and other types of conductor differ slightly for the same copper equivalent conductor size. However, the impedances of the various types of conductor are approximately the same for corresponding sizes and the error is negligible if average values for each copper equivalent conductor size are used in designing the line-mileage scales.

Use of Current Diagrams

In using the current diagrams for determining the fault currents on a distribution system, the starting point is at the source end of the system which is usually the load side of a substation feeding the system. It is necessary to know the equivalent total resistance and total reactance of the system from the generators to the starting point of the distribution system, for the type of fault being calculated and for both maximum and minimum fault-current conditions. All resistance and reactance values must be referred to the voltage base of the current diagrams. In many cases, the impedance of the supply system up to the distribution substation, which is referred to as the source impedance, is negligible and only the impedance of the substation need be considered. When the source impedance is appreciable, data is usually available on either the short-circuit kilovolt-amperes, fault currents, or positive-sequence impedance of the power source at the supply side of the distribution substation. From these data the equivalent source impedance for use in determining the starting points on the current diagrams can be calculated by use of formulas given in Table II, which apply to the most common types of rural distribution systems. Formulas are also given in Table II for determining the equivalent substation impedance which must be added to the source impedance. To determine the starting point on the current diagram, multiply the total source and substation impedance by 0.20 to determine the resistance component and by 0.98 to determine the reactance component. Other proportionate values may be assumed, based on judgment.

The formulas in Table II apply to four-wire wye multigrounded-neutral distribution systems supplied from a three-phase power source through a delta–wye transformer bank, which is the most common type of rural distribution system. The formulas for line-to-ground faults have no significance on delta distribution systems. However, the impedance formulas in Table II for line-to-line and three-phase faults apply to delta distribution systems supplied by a delta-delta substation. Other cases which are less common than those discussed above will not be considered in this paper. The relationship between the formulas in Table II should be noted. Each of the source and substation impedance formulas for line-to-line faults is $2/\sqrt{3}$ times the corresponding formula for three-phase faults. Each of the source impedance formulas for line-to-ground faults is two-thirds times the corresponding formula for three-phase faults and the substation impedance formula for line-to-ground faults is the same as the formula for three-phase faults.

When a fault occurs on the system, there may be some resistance in the fault, which should be considered. The fault resistance could be any value; however, it has been found that 40 ohms is a reasonable value to assume. An assumed value of fault resistance should be added to the resistance of the circuit in calculating minimum fault currents. From the practical standpoint, it is not necessary to consider the fault resistance for each type of fault. On multigrounded-neutral systems, the fault resistance need be considered only on line-to-ground faults because line-to-ground faults are usually used for minimum currents and line-to-ground faults are the only type of fault which can occur at any location on systems containing single-phase lines. On systems where line-to-line or three-phase faults are used for minimum currents, the fault resistance should be considered.

Table I. Impedance of REA Lines in Ohms Per Circuit Mile

Average Values for Copperweld, Aluminum Conductor Steel-Reinforced, and Hard-Drawn Copper, Standard REA Spacing, Earth Resistivity—100 Meter-Ohms

Copper Equivalent Conductor Size	For Line-to-Ground Faults; Single-Phase Impedance With Multigrounded-Neutral Wire		For Line-to-Line Faults; $2/\sqrt{3}$ Times Impedance to Positive- or Negative-Sequence Currents		For Three-Phase Faults; Impedance to Positive- or Negative-Sequence Currents	
	Resistance	Reactance	Resistance	Reactance	Resistance	Reactance
1/0	0.723	1.124	0.643	0.847	0.556	0.733
2	1.00	1.22	1.014	0.890	0.877	0.770
4	1.63	1.31	1.605	0.928	1.388	0.803
6	2.45	1.46	2.546	0.969	2.202	0.838
8	3.74	1.55	4.069	1.001	3.520	0.866
9½	5.04	1.67				
11	7.36	1.704				

Table II. Formulas for Determining the Starting Point on the Current Diagrams

Formulas for Determining the Equivalent Source Impedance When Given Either $I_{3\phi}$, $I_{(L-L)}$, $va_{3\phi}$, or Z_L, of the Power Source at the Supply Side of the Distribution Substation. (For Use on Distribution Systems Supplied by a Delta-Wye Substation)*

Given	For Line-to-Ground Faults	For Line-to-Line Faults	For Three-Phase Faults
$I_{3\phi}$	$Z_s = \frac{2E_n^2}{\sqrt{3}I_{3\phi}E_{(L-L)}}$	$Z_s = \frac{2E_n^2}{I_{3\phi}E_{(L-L)}}$	$Z_s = \frac{\sqrt{3}E_n^2}{I_{3\phi}E_{(L-L)}}$
$I_{(L-L)}$	$Z_s = \frac{E_n^2}{I_{(L-L)}E_{(L-L)}}$	$Z_s = \frac{\sqrt{3}E_n^2}{I_{(L-L)}E_{(L-L)}}$	$Z_s = \frac{3E_n^2}{2I_{(L-L)}E_{(L-L)}}$
$va_{3\phi}$	$Z_s = \frac{2E_n^2}{va_{3\phi}}$	$Z_s = \frac{2\sqrt{3}E_n^2}{va_{3\phi}}$	$Z_s = \frac{3E_n^2}{va_{3\phi}}$
Z_L	$Z_s = \frac{2Z_LE_n^2}{E_{(L-L)}^2}$	$Z_s = \frac{2\sqrt{3}Z_LE_n^2}{E_{(L-L)}^2}$	$Z_s = \frac{3Z_LE_n^2}{E_{(L-L)}^2}$

Formulas for Determining Substation Transformer Impedance in Ohms When Given $\%Z_T$ of Transformer. (For Use on Distribution Systems Supplied by a Delta-Wye Substation)*

Given	For Line-to-Ground Faults	For Line-to-Line Faults	For Three-Phase Faults
$\%Z_T$	$Z_T = \frac{\%Z_TE_n^2}{kva_{1\phi}\,100{,}000}$	$Z_T = \frac{\%Z_T2E_n^2}{\sqrt{3}kva_{1\phi}\,100{,}000}$	$Z_T = \frac{\%Z_TE_n^2}{kva_{1\phi}\,100{,}000}$

Multiply Z_s and Z_T by 0.20 to obtain resistance components and by 0.98 to obtain reactance components. Other proportionate parts of resistance and reactance may be assumed, based on judgment.

List of Symbols

$E_{(L-L)}$ = Line-to-line voltage in volts on supply side of substation.
E_n = Line-to-ground voltage in volts on load side of substation.
$I_{3\phi}$ = Three-phase fault current in amperes on supply side of substation.
$I_{(L-L)}$ = Line-to-line fault current in amperes on supply side of substation.
Z_s = Equivalent impedance in ohms per phase of source at load voltage.
Z_1 = Positive-sequence impedance in ohms of source at substation.
Z_T = Equivalent impedance in ohms per phase of substation transformers.
$\%Z_T$ = Per cent impedance of substation transformers.
$va_{3\phi}$ = Three-phase short-circuit power in volt-amperes on supply side of substation.
$kva_{1\phi}$ = Substation transformer capacity in kilovolt-amperes per phase.

* Formulas for line-to-line and three-phase faults also apply to delta distribution systems supplied by a delta-delta substation. Formulas for line-to-ground faults have no significance on delta systems.

The procedure for calculating fault currents on the current diagrams is as follows:

1. Locate the point for the equivalent total impedance of the source and distribution substation by laying off the resistance along the horizontal scale and the reactance along the vertical scale. Locate the total impedance for both maximum and minimum fault-current conditions. Read the fault currents on the circles.

2. Draw a line from the points located in step 1 to the right, parallel to the line-mileage scale for the conductor size in the first section of line away from the substation. These lines can be drawn by manipulation of two drafting triangles, a rule and a triangle, or any other graphical means.

3. Using a compass, or dividers, and the mileage scale for the proper conductor size, set the instrument to the number of miles from the substation to the first point out on the system where it is desired to know the fault currents. Lay this distance off from the points located in step 1 along the lines drawn in step 2.

4. Read the fault currents on the circles.

5. Repeat the above procedure for the next point farther out on the system where it is desired to know the fault current. If the conductor size on the line changes, draw a new line on the diagram from the point for the end of the first conductor size, parallel to the proper mileage scale. Repeat until all points on the system, at which fault current values are desired, have been plotted on the diagram.

Although a current diagram is designed for a specific system voltage, it can be used for any system voltage provided the physical characteristics of the system are such that the impedance per mile of line is the same as the impedance used in designing the line-mileage scales. The fault current is directly proportional to the system line-to-neutral voltage. Therefore, fault currents read on a current diagram for a specific voltage can be converted to another voltage by multiplying them by the ratio of the line-to-neutral voltage of the system being studied to the line-to-neutral voltage for which the diagram was designed. In determining the starting point when the actual system voltage is different than the voltage for which the current diagrams were designed, the source and substation impedances to the starting point should be referred to the actual system voltage.

Illustrative Example

This example is given for the purpose of illustrating the graphical method of calculating fault currents on a distribution system. Only line-to-ground fault currents are calculated because the procedure for calculating each of the different types of fault currents is the same.

A one-line diagram of a hypothetical system is shown in the upper left-hand corner of Figure 3. The system is a multigrounded-neutral system, having a nominal voltage of 7,200/12,470 volts. It is supplied from a 33-kv transmission line through a bank of three 150-kva single-phase 33-kv to 7.2-kv transformers, each having an impedance of five per cent. The short-circuit kilovolt-amperes on the transmission line at the location of the substation is 20,000 kva. The problem is to determine the maximum and minimum fault currents at the points indicated on the diagram of the system.

Using the proper formula from Table II, the source impedance is:

$$Z_s = \frac{2\times(7{,}200)^2}{20{,}000{,}000} = 5.2 \text{ ohms}$$

The substation impedance is

$$Z_t = \frac{5\times(7{,}200)^2}{150\times100{,}000} = 17.3 \text{ ohms}$$

The total equivalent impedance of the source and substation referred to the distribution-system voltage is 22.5 ohms. Assuming the resistance component to be 0.20 times total equivalent impedance and the reactance component to be 0.98 times the total equivalent impedance, the total resistance to the load side of the substation is 4.5 ohms and the total reactance is 22.1 ohms which are the values used for the starting point on the current diagram for maximum fault current. Assuming a 40-ohm fault resistance, the starting point for minimum fault currents is 44.5 ohms resistance and 22.1 ohms reactance.

Table III. Data for Illustrative Example

Point	Preceding Point on Line Toward Substation	Miles From Previous Point on Line Toward Substation	Copper Conductivity Size—Section From Previous Point	Maximum Line-to-Ground Fault Current, Amperes	Minimum Line-to-Ground Fault Current, Amperes
Substation				320	145
A	Substation	13	4	153	94
B	A	7	6	110	75
C	A	10	6	98	69
D	C	5	8	79	58
E	A	19	6	73	55
F	E	9	6	59	46
G	F	8	8	47	38

The distance between the points on the system at which fault-current values are desired and the copper equivalent-conductor size in each section are given in Table III. The graphical calculation of the fault currents is shown on the current diagram in Figure 3 and the fault current values are tabulated in Table III.

Alternate Design for Line Mileage Scales

There is an alternate design for the line-mileage scales which some engineers may prefer to use. Instead of putting the mileage scales on the current diagrams, a right triangle similar to a drafting triangle can be constructed for each line-mileage scale. A separate triangle is necessary for each conductor size and for each type of fault. The triangles should be designed as described previously for designing the line-mileage scales on the current diagrams with the hypotenuse of each triangle calibrated in miles. These triangles can be used directly on the current diagram to draw lines between points at the proper slope and to lay off mileage distances between points.

Change in Source or Substation Impedance

If the source or substation impedance is changed, as in the case of installing additional generating capacity or installing larger transformers in the distribution substation, it is easy to determine the new fault currents on the distribution system, if a fault-current study of the system has been previously made by the graphical method. It is necessary to calculate the new equivalent resistance and reactance up to the beginning of the distribution system and locate the new starting points on a current diagram. Lay the new current diagram over the old current diagram and line up the starting points. Then trace the old fault current points and lines between the points onto the new current diagram. The new fault current values can then be read from the new current diagram.

Conclusion

The accuracy desired depends largely upon the scale chosen for designing the current diagrams. It is believed that sufficient accuracy can be obtained if the diagrams are prepared on standard 11 1/2-by-17-inch graph paper calibrated ten to the inch. A scale of one-half inch equals ten ohms can be used. If the system consists mainly of conductor sizes larger than number 4 copper equivalent, it is recommended that a scale of one inch equals ten ohms be used.

Separate current diagrams should be used for each substation. In cases where the distribution system is large and there are a large number of locations on the system where it is desired to know the fault currents, it is suggested that separate current diagrams be used for each one of the main feeder lines, in order to prevent confusion which may result from too many points on the same current diagram.

When the fault currents on a system have been calculated by the graphical method, the current diagrams will prove to be valuable in the operation of the system. Each current diagram gives a visual picture of fault current conditions at any location on the system.

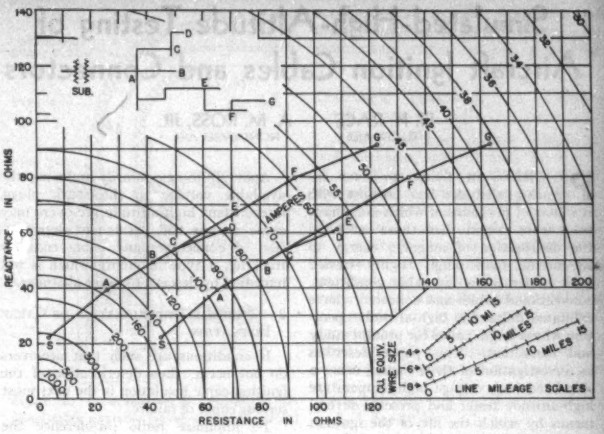

Figure 3. Illustrative example showing one-line diagram of a 7,200/12,470-volt system and graphical calculation of line-to-ground fault currents

Calculations above the current scale are for maximum fault currents and calculations below the current scale are for minimum fault currents. Refer to Table III for other data

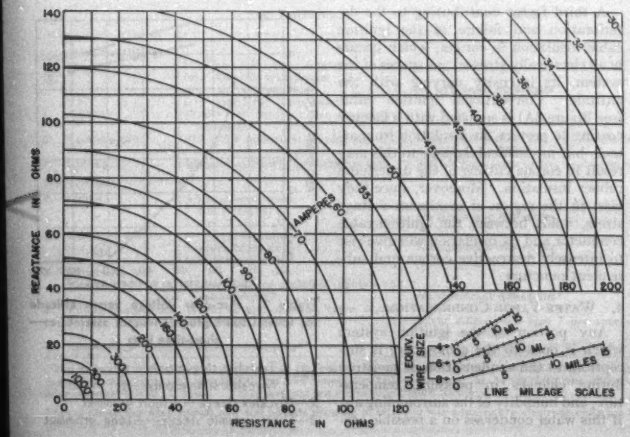

Figure 2. Typical 7,200-volt current diagram with line-mileage scales for calculating three-phase fault currents

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Simulated-High-Altitude Testing of Aircraft Ignition Cables and Connectors

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PROGRESS in flying to ever increasing altitudes has brought with it a host of problems of which none have been more urgent than those involving the distribution of magneto energy to the aircraft spark plug. Highly stressed even under more favorable conditions, conventional cables and connectors have exhibited failures in high-altitude operation whose origin called for prompt study and correction. This paper describes an investigation of these causes using a simulated high-voltage high-temperature high-altitude tester and presents several means by which the life of the ignition system may be appreciably extended.

The Problems

1. Arc-over at Connectors

In order to fly aircraft with high-voltage ignition systems to altitudes greater than about 30,000 feet, one of the technical problems which must be solved is the prevention of arc-over at any point in the ignition system, since such arc-overs prevent the plugs from firing. The conventional ignition system is assembled with at least three components—magneto, ignition wire, and spark plug—with detachable connectors between them. In general these connectors are not gas tight so that any spaces not filled with solid dielectric contain air at a pressure determined by the altitude. The effect of this is illustrated in Figure 1 by curve 1 which shows how the arc-over voltage of a number of types of connectors decreases as the air pressure is decreased to simulate high altitude. This effect represents an inherent limitation of the conventional high voltage ignition system.

The engine manufacturers have stated that the maximum voltage which may be required at the plug for the most severe conditions of engine operation is of the order of 12.7 kv peak. Figure 1 shows that this voltage cannot be obtained with conventional connectors above 20,000 to 25,000 feet altitude. However, if the engine requires only nine kv peak, standard connectors will not arc-over up to 40,000 feet.

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Apart from temporarily reducing the available voltage to the spark plugs, intermittent high-altitude arc-overs may cause serious and permanent deterioration of connectors and cable ends by tracking, a type of failure which is not remedied by descent to lower altitudes.

2. Thermal Deterioration of Cable Insulation

If conditions are such that arc-overs do not occur, then deterioration of the ignition-cable insulation is the next most serious cause of failure.

To minimize radio interference the ignition cables must be completely encased in a metal shield (called the harness) from the distributor to the spark plug. Figure 2 shows a conventional spark-plug connection, at which point the highest temperatures are reached.

Engine manufacturers have stated that the temperature at the bottom of the spark plug well may be as high as 400 degrees Fahrenheit and in the elbow between 250 and 350 degrees Fahrenheit. Accelerated chemical decomposition at these temperatures causes deterioration of all conventional organic insulation. However, since there are large differences in the rates of oxidative and thermal decomposition among available rubber-like insulating materials, a proper choice of cable insulation and sheath materials is very important.

3. Corona Cutting of Cable Insulation

A third factor contributing to the deterioration and failure of the ignition cable insulation is corona, which occurs in all electrically stressed gas spaces of the system, its intensity varying with the altitude. Conventional ignition cable (see Figure 3A) is supplied with a lacquer coating to protect the insulation from attack, but mechanical damage to this may result in corona cutting of the underlying rubber insulation. Moreover, since they exist in the region of maximum voltage stress, voids between the ignition-cable conductor and its insulation will give rise to intensely destructive corona and subsequent puncture.

4. Water-Vapor Condensation

Any portion of the ignition system which is open to the atmosphere is susceptible to the condensation of moisture during changes in pressure, temperature, and humidity of the surrounding air. If this water condenses on a possible arc-over or creepage path of the insulation, as in connectors or spark-plug wells, the arc-over voltage will be greatly reduced.

Possible Solutions

Supercharging (to Correct 1, 3, and 4)

Although arc-over, corona, and entrance of moisture could be eliminated by supercharging the entire ignition system, this is not desirable if other solutions can be found because of the large supercharger capacity required and the likelihood of leaks or mechanical damage at any one of the many connections. A single break would destroy the high-altitude performance of the entire system. Furthermore, supercharging the harness appears unnecessary because of other possibilities listed below.

Filling of Manifold (to Correct 3 and 4)

Complete and permanent filling of the harness manifold with a void-free dielectric will eliminate corona and moisture difficulties. This has been made possible by the development of polymerizable liquids suitable for impregnating completely wired manifolds. One of these is at first sufficiently fluid to permit ready vacuum filling, and is converted by a brief bake at moderate temperatures to a soft elastic infusible gel of excellent electrical properties. Several thousand units of one make of this type have been put in service with no failures of manifold cables as yet reported.

Filling of Detachable Leads (to Correct 3 and 4)

Similarly, improved leads (from manifold to spark plug) have been developed. These are detachable from the manifold proper and carry an ignition cable and connectors completely molded into a Neoprene-filled flexible shielding con-

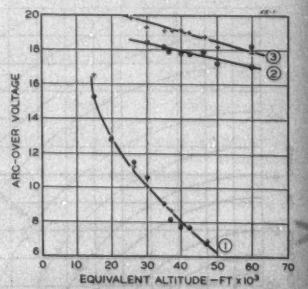


Figure 1. Arc-over voltage versus altitude for several spark-plug-connector assemblies—short-time tests

1—{ Textolite sleeve only—⊙ / Mycalex sleeve only—+
2—Mycalex sleeve—+short grommet
3—Short ceramic sleeve—+long grommet

duit. Tests are described in the section "Experimental—Results on Standard Cycle."

Filling of Connectors (to Correct 1, 3, and 4)

By filling all spaces in the spark-plug well and connector with a plastic semi-solid dielectric, arc-over may be made more difficult even at high altitudes. A compound of suitable electrical characteristics and excellent heat stability has recently been made available for this purpose.

Inorganic Terminal Sleeves (to Correct 1 and 2)

Until recently organic terminal sleeves have been generally used. These have very poor arc resistance so that if arc-over of appreciable intensity occurs the insulation becomes carbonized and is permanently destroyed. Recently inorganic terminal sleeves made from porcelain and Mycalex have been introduced. These do not change the arc-over characteristic of an open assembly at high altitude (see Figure 1), but the inorganic materials are not damaged by this arcing and will function satisfactorily again below the critical arc-over altitude. Another very important characteristic is that these inorganic materials do not deteriorate with time at the high temperatures existing in spark-plug wells.

Neoprene Sealing Grommets (to Correct 1 and 4)

Neoprene is a synthetic rubber of greatly enhanced resistance to corona and can be compounded to have excellent heat resistance. It is, therefore, an excellent gasket material to seal connectors against water vapor from without or loss of pressure from within, thus improving the arc-over voltage characteristics of the sealed assembly as indicated in Figure 1, curves 2 and 3. This advantage is not always retained permanently in service as will be brought out in the discussion of our experiments, but it is helpful within the expected life between necessary disassemblies.

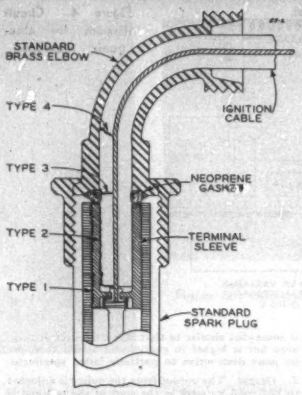


Figure 2. Cross section of plug-elbow-terminal-cable assembly (seven-millimeter cable)

Jagged lines denote possible paths of failure

Inorganic Elbows (to Correct 2 and 3)

Solid spark-plug elbows have been made with Mycalex-insulated cores. These accomplish the desirable result that no organic material be located in the high temperature region of the spark-plug well.

Composite Terminals (to Correct 1, 2, 3, and 4)

A neoprene boot of one millimeter wall-thickness, approximately the length of the elbow, is slipped over the end of five-millimeter cables to adapt them to seven-millimeter connector assemblies. During the course of our investigation a new terminal was developed in which the neoprene adapter-boot, a neoprene grommet, and a Mycalex terminal sleeve were molded integrally with the addition of a molded-in copper ring for the gasketing surface. This is a marked improvement and will be discussed in detail in connection with our test results.

Improved Ignition Cables (to Correct 1, 2, 3, and 4)

This major improvement will be discussed in detail. The simulated flight tester, to be described, has very clearly demonstrated the superiority of the new constructions.

Simulated Altitude Testing—Apparatus and Procedures

The urgency of the problem of determining the causes of cable and connector failures and of developing improved assemblies required the adoption of a laboratory apparatus for reproducing, in at least some of its essential respects, the operation of an actual aircraft ignition system. This was not intended to replace individual property tests on construction materials but rather to provide laboratory information in advance of engine tests in the field.

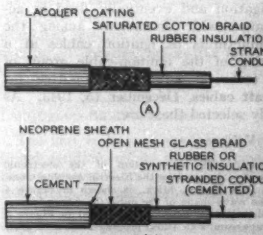


Figure 3. Conventional lacquered-braid ignition cable (A) and improved high-altitude ignition cable (B)

Essentially the test apparatus developed consists of: a means of applying a controlled, pulsating voltage to a shielded cable-connector-spark-plug assembly, a means of heating the spark plug to a controlled temperature, and a

Table I

Forty-Two Lacquered-Braid Cables

	Test Variations	Effect
Operating conditions:		
1. Voltage	12.7 kv peak; three sources: (a). 60 cycle transformer (b). aircraft magneto (c). electronic interrupter	No significant differences
2. Altitude	47,000 feet, constant (ten centimeters pressure)	
3. Temperature	270–400 F maximum (at plug elbow)	Longer life below 300 F; differences slight above 300 F
4. Cycling	Irregular or hourly, temperature only	Most failures occur in first cooling period
Components:		
1. Cables	All lacquered-braid: 7 mm (2 types) 5 mm (1 type)	No significant differences
2. Terminal sleeves	One inch Mycalex	
	9/16 inch Mycalex	No significant differences
	9/16 inch porcelain	
3. Grommets and boots*	Appropriate to terminal sleeves and cables above*	No significant differences*
4. Filling compounds	None, or one of seven types organic semisolid	Slight differences; type 7 has superior heat stability
5. Spark plugs**	1 type aircraft plug**	

*The necessity of having grommets to seal the connector was shown by four additional tests in which grommets were omitted: at 47,000 feet two assemblies failed at once; at 35,000 feet one failed at once, another lasted 1.7 hours. These tests are not included in Figure 10, curve 1.

**Plug electrodes were spread and 400 pounds pressure of nitrogen was admitted to electrode chamber to prevent plug from firing.

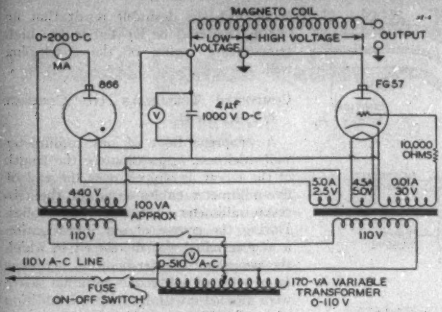


Figure 4. Circuit diagram for electronic interrupter

means for maintaining the system at a controlled external pressure. Early in our experimentation, it was noticed that certain types of assemblies failed more rapidly when the temperature and pressure were varied than they did under constant conditions. Repeated expansion and contraction caused leaks to develop after which electric discharges resulted in failure. Since fluctuation in these variables is characteristic of actual flight conditions a cyclic procedure was adopted and appropriate equipment installed.

Standard Test Conditions and Equipment

The original apparatus and procedures were varied during the course of the investigation and eventually fixed in accordance with discussions among the manufacturers of ignition cables at a meeting of the ignition-cable group of the technical advisory committee for aircraft cables, December 15, 1943. As finally selected these are:

(*a*). Voltage:

1. *Source.* The construction of the electronic interrupter, designed by the Electric Autolite Company, Port Huron, Mich., is shown in Figure 4 and the wave shape of the pulse (as drawn from a cathode-ray oscilloscope) is exhibited in Figure 5 in comparison with those produced by a 60-cycle transformer and an aircraft magneto, the other voltage sources tested. The pulse from this device is somewhat similar to that from the aircraft magneto but is higher in energy and would therefore be more destructive to partially failed specimens.

2. *Output.* The output from the pulser is adjusted to 12.5 ± 0.5 kv peak at the start of the test and is permitted to fall as it will. A failure is considered to have occurred when the voltage falls to 5 kv peak.

(*b*). *Pressure.* The vacuum regulator is adjusted so that the minimum pressure reached is 10 ± 0.5 centimeters of mercury.

(*c*). *Temperature.* The input to the heaters is such as to raise the temperature of the spark plug (measured at the copper gasket) to 500 ± 10 degrees Fahrenheit and the elbow (measured at its midpoint) to 325 ± 5 degrees Fahrenheit, these being the maximum temperatures measured in vacuo.

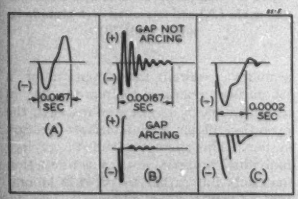


Figure 5. Wave shapes for three voltage sources sketched from high-voltage cathode-ray oscilloscope

A—Sixty-cycle ignition transformer
B—Thermionic interrupter
C—Aircraft magneto

(*d*). *Cycling.* The following switching schedule is used:

Time (Minutes)	Heat	Vacuum	Voltage
0	On	On	On
45	Off		
90	On		
120	Off		
135	Off		
180	On	On	On

The nature of the equipment is well illustrated by our most recent setup. A simplified block diagram for this is given in Figure 6 which indicates its construction and operation. It will be noted that the equipment is entirely automatic, the vacuum and heat cycling being controlled with an electric clock by cam-operated switches, and the voltage, temperature, and pressure being recorded automatically. A special contact on the voltage recorder shuts down the equipment when the failure voltage (five kilovolts peak) is reached.

Figures 7 and 8 are photographs of part of this equipment. In Figure 7 the electronic interrupter can be seen in the right-hand corner of the cage. At the top is the capacitance divider from which crest voltage readings can be taken on a vacuum-tube voltmeter.[1]

The right-hand plate shows the spark

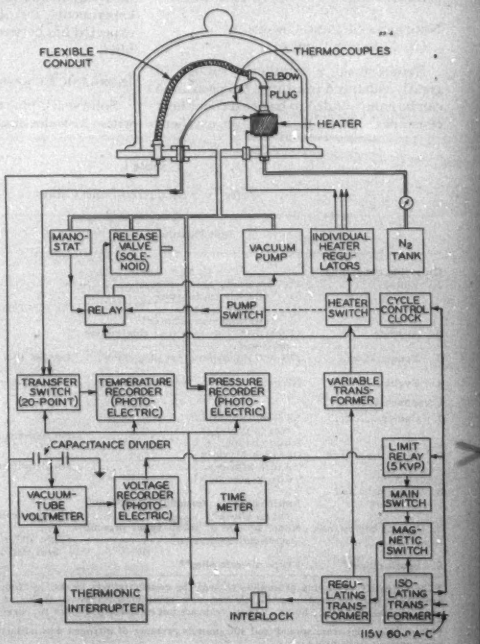


Figure 6. Block diagram of automatic cycling and recording simulated-high-altitude-test equipment

Figure 7. Laboratory installation showing two three-sample test units, high-voltage power supply, and capacitance divider

Figure 8. Laboratory installation showing recording and control instruments

plugs inserted in their blocks (with heaters removed). In order to prevent sparking these plugs have their outer electrodes machined back and a pressure of 20 pounds per square inch of nitrogen is applied to the block. On the left the bell jar is completely set up with cables and shields in place and heaters and thermocouples connected.

Figure 8 exhibits the working bench, showing from right to left:

1. Electronic relay, operated from contact on voltage recorder to shut down the entire set up at failure.
2. Voltage recorder.
3. Vacuum-tube voltmeter.
4. Pressure recorder.
5. Temperature recorder.[2]
6. Motor-driven thermocouple transfer switch which scans each of 20 thermocouples every five minutes (12½ seconds reading, 2½ seconds in transit between couples).

Voltage regulators, presssure regulator, heater-current adjustments, and so forth, are underneath this bench.

An example of the voltage-temperature-pressure records produced by this equipment is given in Figure 9.

Examination of Samples After Failure

It was found early in the investigation that failures may occur in several ways. The importance of making and recording "post-mortem" examinations in such a study cannot be overemphasized as a means of learning how and why failures occur.

For convenience failures are grouped into four types:

Type 1 represents arc-over or creepage failure between the inside surface of the spark plug well and the outside surface of the terminal sleeve.

Type 2 represents arc-over or creepage failure between the inside surface of the terminal sleeve and the surface of the ignition cable.

Type 3 represents puncture of the cable under the gasket.

Type 4 represents puncture of the cable anywhere back of the gasket.

These failure types are illustrated in Figure 2. When the track or puncture is not visible, it can often be detected very readily by the use of a high-frequency spark coil (such as glass blowers use for detecting leaks in high-vacuum systems); the discharge from this travels visibly but harmlessly to any conducting path or puncture.

Experimental—Early Results

The major problem facing the investigation at its inception was the fixing of the many variables involved in test conditions and component parts of the simulated ignition assembly. The early results, all obtained before the standard cycling procedure was finally devised, fall naturally into two groups.

Lacquered-Braid Cables

The first tests were made on conventional ignition cables of the construction represented in Figure 3A. During this group of runs many variations of procedure and assembly components were used. These are summarized in Table I and the results on test life are plotted in Figure 10, curve 1.

No lacquered-braid cable withstood more than 22 hours of this treatment, as Figure 10, curve 1, indicates. In general, the failed samples exhibited very close resemblance to samples which had failed in actual high-altitude engine tests, the cotton braid being badly charred and the lacquer coating blistered and decomposed in the high-temperature region of the plug well. It was evident that this decomposition was caused by tracking as much as by the externally applied heat. Of all failures, approximately 60 per cent were due to arc-over and tracking, and 40 per cent to cable punctures.

Neoprene-Sheathed Cables

Because of the results summarized in Table I, subsequent experiments were

Table II

Forty-Six Neoprene-Sheathed Cables

	Test Variations	Effect
Operating conditions:		
1. Voltage	12.7 kv peak; electronic interrupter	
2. Altitude	47,000 feet (ten centimeters pressure)	
3. Temperature	350 F maximum (at plug elbow)	
4. Cycling	Hourly, heat only	
Components:		
1. Cables	All neoprene-sheathed: Five mm (six types) / Seven mm (eight types)	Some types markedly superior
2. Terminal sleeves	One inch Mycalex / ⅝-inch Mycalex	No significant differences
3. Grommets and boots*	Appropriate to cables and terminal sleeves*	No significant differences
4. Filling compounds	None, or one of three types organic semisolid	No significant differences
5. Spark plugs**	One type aircraft plug**	

*One additional sample (not plotted) run without grommet lasted 1.2 hours.

**In the course of running this group the nitrogen pressure was reduced from 400 pounds to 25 pounds and the plug electrodes machined off to prevent firing.

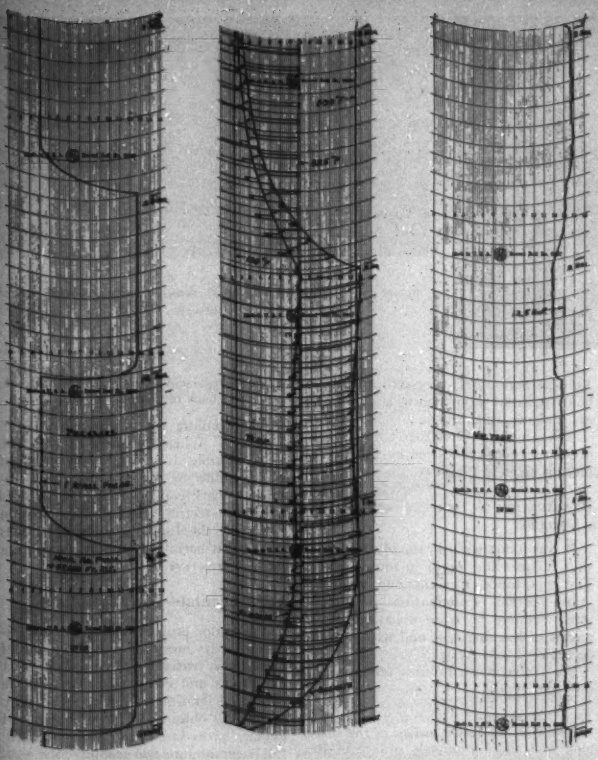


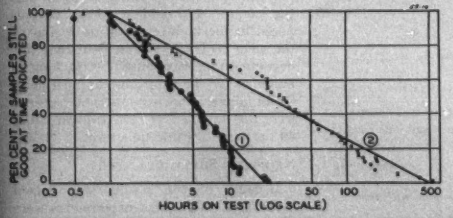
Figure 9. Pressure, temperature, and voltage records for automatically controlled simulated-high-altitude tester

run at constant voltage (12.7 kv peak) from a single source (electronic interrupter) and at constant altitude (47,000 feet). The maximum temperature measured at the elbow was set at 350 degrees Fahrenheit and a time switch installed to turn the heaters on for one hour then off for an hour continuously. This cycling, producing expansion and contraction of the connector assemblies, is a severe test of the effectiveness of connector sealing.

The neoprene-sheathed cables, though varying from type to type, immediately exhibited their inherent superiority. The variables of operation during this second group of tests is summarized in Table II, and the results plotted in Figure 10, curve 2. Most of the cables conform to the construction pictured in Figure 3B.

The superiority of the neoprene-sheathed cables, exhibited strikingly in

Figure 10. Test life of lacquered-braid and neoprene-sheathed cables—early results



Curves 1:
⊙—Lacquer - braid arc-over failures (24)
⊗—Lacquer - braid cable failures (18)

Curves 2:
•—Neoprene-sheathed arc-over failures (26)
×—Neoprene-sheathed cable failures (20)

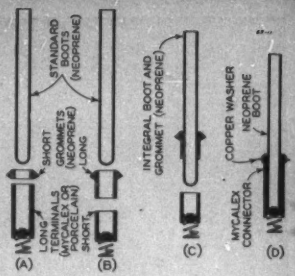


Figure 11

A and B—Standard five-millimeter terminal assemblies
C—Integral boot and grommet connector assembly
D—Improved composite terminal assembly

Figure 10, curve 2, is the result of three major factors. First is the elimination of the cotton braid, which, we have seen, is a notable source of tracking failures, either through moisture absorption or gradual carbonization from arc-over or external heat. It is of interest in this connection that cables lacquered directly over the rubber insulation behave rather well on this test, one sample lasting 65 hours. However, this construction is mechanically undesirable, the lacquer pulling loose from the rubber on bending or stretching. It would seem best to eliminate braids altogether, but this is not satisfactory for other reasons. In particular, a braid is required to strengthen the cable against horizontal tension encountered in re-wiring harness. Seventeen samples of neoprene-sheathed cable without braid were tested with promising results on electrical life, but these are all subject to injury on pulling, the insulation tending to stretch loose from the core. The open-mesh glass braid shown in Figure 3B appears to be the best compromise.

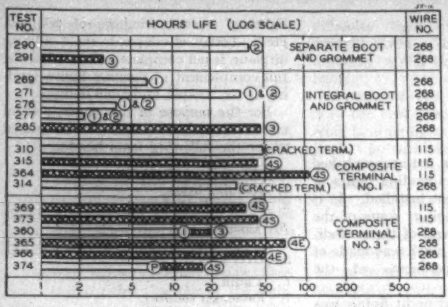
In the second place, the inherent heat and ozone resistance of the best quality neoprene sheaths exhibits itself to advantage in this set of tests.

Finally, the construction of this cable is better suited to proper sealing of the spark-plug well. The open-mesh glass braid is well imbedded in the insulation during the vulcanization process and in some makes was found to be thoroughly sealed.

Other matters, for example the problem of sealing the insulation to the conductor to prevent internal voids and consequent corona, are common to both cable types. The details of their construction have been discussed elsewhere.[3]

Discussion

We may conclude, then, from this survey, that the simulated-altitude test is capable of producing rapid failures of



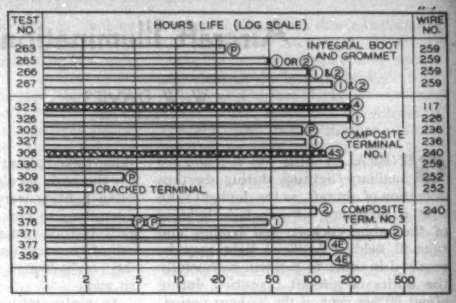


Figure 12. Test life of five-millimeter lacquered-braid cables

Standard cycling procedure

Figure 13. Test life of five-millimeter neoprene-sheathed cables

Standard cycling procedure

inferior ignition assemblies which resemble those found in actual operation; that the electronic interrupter used is a satisfactory substitute for the aircraft magneto (which would require excessive servicing for continuous laboratory operation); and that cycling of temperature is essential in reproducing one of the drastic conditions of aircraft operation.

Although there are marked differences between different makes, a good neoprene-sheathed cable should outlive the best lacquered-braid cable by a large margin. Sealing of the connector by some type of grommet is essential, and there is room for considerable improvement in the effective life of available grommets. This is demonstrated by the wide scattering of arc-over failures (types 1 and 2) exhibited in Figure 10. The nature of this sealing compound or its absence seems to be secondary to the effectiveness of the seal and more or less independent of it (the two best assemblies using neoprene-sheathed cable had no filling compound). All terminal sleeves tested were inorganic, and no differences could be demonstrated between the various types. It was noticed, incidentally, that many spark plugs were found to leak air at the conclusion of the test period. This is said, however, not to occur very frequently in actual operation.

Experimental—Results on Standard Cycle

Composite Terminals

The experiments previously discussed have demonstrated that with all types of available connector assemblies the majority of failures are caused by arc-over (types 1 and 2). To eliminate the type-2 failures a terminal was designed for five-millimeter cables in which the neoprene adapter boot, the grommet, and the Mycalex terminal sleeve were molded integrally, the boot being firmly bonded to the interior of the inorganic sleeve. Later this was improved by including a copper-ring washer molded into the grommet to give better electrical contact (for better radio shielding) and to relieve the soft neoprene grommet of abuse caused by cycling of temperature or by removing and replacing the connector incidental to inspection and service. This improved design is shown in Figure 11 in comparison with three other types of connector assembly. As subsequent data demonstrate, it materially reduces the number of arc-over failures.

Five-Millimeter Cables

Both lacquered-braid and neoprene-sheathed types were tested according

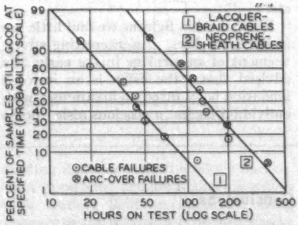


Figure 14. Distribution plots—test life of five-millimeter lacquered-braid and neoprene-sheathed cables with composite terminals

1—Lacquer-braid cables
2—Neoprene-sheath cables
⊙—Cable failures
⊗—Arc-over failures

to the standard cycling procedure, using four different types of terminal:

(*a*). Standard adapter boot plus grommet (Figure 11A and B).

(*b*). Boot and grommet molded integrally (Figure 11C).

(*c*). Composite terminal.

(*d*). Composite terminal with copper gasket (Figure 11D).

The results of the tests for lacquered-braid cables are given in Figure 12 and for neoprene-sheathed cables in Figure 13.

In these charts the length of each bar is proportional to the logarithm of the test life for the sample numbered in the left-hand column. The type of failure is indicated by a number at the end of the bar, these having the same significance as the failure types indicated in Figure 2. Type *P* represents a spark-plug failure.

In several of these assemblies, it was possible to continue testing after a spark-plug failure by replacing the defective plug, and after a type 1 failure by cleaning the terminal sleeve and plug well and renewing the filling compound. Tests marked "cracked terminal" were made with defective experimental terminals and actually failed by tracking along a crack in the Mycalex sleeve.

The superiority of the neoprene-sheathed cables is indicated by examination of Figures 12 and 13, and there is a striking improvement of the lacquered-braid cables when made up with composite terminals. A comparison of neoprene-sheathed and lacquered-braid cables assembled with composite terminals may be made by plotting the life times of all samples tested to completion (omitting those which failed because of cracked terminals) as in Figure 14. The two curves are linear and parallel so that their displacement (0.52 log units) permits us to say that the life expectancy of a neoprene-sheathed cable is approximately $3^1/_2$ times that of a lacquered-braid cable under these conditions.

Seven-Millimeter Cables

The results of 18 tests on seven-millimeter cables (which are too large in cross section to permit the use of boots or composite terminals) give an equally favorable comparison for neoprene-sheathed cables as against lacquered-braid cables.

Aircraft Illumination

W. W. DAVIES
NONMEMBER AIEE

GENERALLY little use is found for auxiliary lighting during daytime operation of aircraft, as the daylight is all that is necessary for adequate lighting of the cabin, cockpit, and landing and take-off fields. Artificial light may be required in order to perform successfully the duties of aircraft operation during about 60 per cent of the 24-hour period. Though normal daylight may be effective for more than 50 per cent of the day throughout the year, actually artificial lighting is required at the dawn and dusk periods inasmuch as the normal amount of daylight is not adequate. It is obvious of course that it is highly impractical to provide over-all lighting to duplicate daylight. Therefore, localized artificial lighting is the best approach to the problem. With proper illumination in the cockpit, however, normal operating conditions are carried out equivalent to those of daylight hours. Artificial lighting is definitely needed so that all functions can be accomplished without delay during the hours of darkness.

When the air-transport industry was in its infancy, night operation was a thing talked about but not accomplished On the early airplanes landing lights or cabin lighting were not installed. It is interesting to look back at some of the early history. In several of the periodicals of the early days much was made of the night-flying experiments of the air mail.

An early attempt at night flying was made between Cheyenne and Chicago in 1921 by pilot Jack Knight of the air-mail service. The first night-flying section of the air mail was set up in 1923 in order to complete a regular coast-to-coast operation without interruption for darkness. The night route was between Chicago and Cheyenne. It is interesting to note that much is made in the historical records of the fact that Air-Mail Pilot H. T. Lewis spent considerable time with General Electric Company engineers devising and producing a new and satisfactory type of "wing headlight" (which was carried on the tip of the airplane wing) for the use of airplanes about to make a landing at night. Of further interest, in 1926 one of the highlights of one manufacturer's description of the characteristics of his craft was that it was "complete with night-flying equipment including landing lights, running lights, etc. . . ."

Even of cabin lighting we find little use in the early days. An interesting advertisement of an airplane in the early 20's advised that, "the cabin is an inclosed limousine body fitted up luxuriously with individual chairs, a spacious aisle, 'dome lighting,' curved windows of celluloid, etc." Today, of course, to most of us an airplane is not complete unless it has the full complement of running lights, landing lights, cockpit, and cabin lighting.

For the purpose of this paper, general aircraft illumination will be considered under the following main headings:

A. Flight operations
1. Landing lights.
2. Navigation lights.

B. Cockpit
1. Instruments.
2. Over-all.

C. Cabin
1. Passenger comfort.
2. Attendant service.

D. Ground servicing
1. Loading and unloading—passengers and cargo.
2. Aircraft servicing.

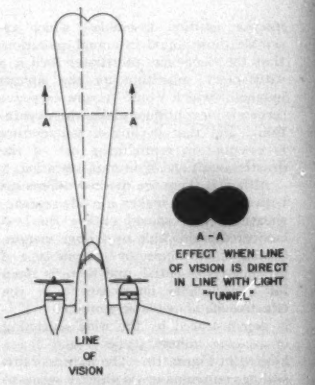


Figure 1. Present nose landing lights

Paper 45-6, recommended by the AIEE committee on air transportation for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted June 1, 1944; made available for printing November 4, 1944.

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The majority of the failures (12 out of 15) were arc-over types but four of the neoprene-sheathed assemblies had not failed after 400 hours and two were still running after 500 hours of test. The longest-lived lacquered-braid cable ran 92.2 hours.

Filled Leads

Twelve sets of this type were tested according to the standard procedure. One group of six gave entirely arc-over failures between 23.5 and 84.0 hours. Another group of three (with other terminal assemblies) had excellent test lives, one failing by puncture after 252 hours, the other two still running at 675 hours when the test was discontinued. Only one short-time puncture (37.7 hours) was encountered. Evidently with suitable terminal fittings these leads have considerable promise.

Conclusions

The simulated-altitude test equipment is a means for reproducing certain aspects of actual flight conditions. In this way it has exposed weaknesses in cables and connector assemblies which might not otherwise have been so readily understood or remedied. It has shown the necessity for sealing spark-plug wells and has led to an improved terminal construction. The superiority of neoprene-sheathed over lacquered-braid ignition cables has been amply demonstrated.

Even for the best types of assembly prepared so far the variability of results is great (roughly a ten-to-one ratio in test life), and this indicates a need for new insulating and gasketing materials and for improved design of component parts.

The simulated-altitude test is not a substitute for regular specification testing for acceptance or manufacturing control, but, rather, a useful adjunct to them. However, its most valuable function is to give information on newly designed assemblies in advance of actual engine tests. The development of new insulating materials or of new cable or connector constructions can certainly be accelerated through its use.

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Flight Operation

Landing Lights

The present functions of the landing lights are:

(*a*). To aid the performance of the landing by lighting the immediate landing path for the pilot.

(*b*). To identify the airplane in the maneuver and approach by means of the lighted landing lights. These are turned on several miles from the field to avoid collision with other aircraft.

Landing lights generally have been positioned in either the nose or the wing. Although the positioning of the lights

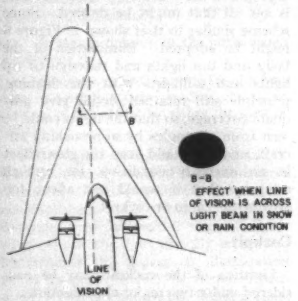

Figure 2. Present wing landing lights

in the nose satisfies both of the aforementioned desired functions, there is a definite objection to their use in fog, or snow, or rain. The light is reflected from the individual particles and in effect detracts from what can be seen through the beam, that is, when one is looking directly down the beam or "tunnel of light." See Figure 1. This is very undesirable, and the author knows of no satisfactory solution which is immediately available. Actually, in many cases an approach has been made in bad weather conditions, and the pilot has been able to see a good portion of the surrounding obstructions and outline of the major objects about the field with the lights off. However, as soon as the lights have been snapped on, he is unable to see more than a few feet beyond the airplane. It has been found, however, that this condition can be improved materially when the lights are located in the wing some distance outboard from the fuselage. This can be explained best by reference to Figure 2. When the pilot is making the landing, if the left landing light is shut off, he in effect looks through and not down the opposite beam of light and does not get the direct reflection of light upon the particles of snow, fog, or rain. By passing the line of vision then, across the light beam, the runway and small objects on it can be seen with less difficulty than when one is looking straight down a "tunnel of light" which normally would be formed by the nose lights.

Experience has indicated that probably the best direction for the beams of wing landing lights is as shown in Figure 2, that is, with the left landing light, or pilot's light, pointing ahead so that light is best for the pilot, and the right landing light, or copilot's light, converging on the same spot. The main advantage of this is to protect the pilot's vision for all conditions of the operation. As example, in the event of a failure of either light, the lighted portion of the runway would be the same in either case. It is appreciated, however, that this is a compromise condition as this is an undesirable situation from the standpoint of the copilot. Several cases have been encountered, however, of lights burning out at the time of landing, and some protection must be given. One possibility is to direct both lights as shown in Figure 3 giving a wider spot on the runway; giving good

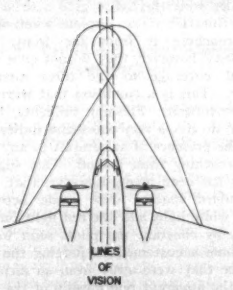

Figure 3. Proposed wing landing lights (with lamp burnout protection)

landing light for both the pilot's and copilot's position; and incorporating within each landing light an automatic lamp changer of the type that is used in airway beacons at the present time. The unit could be such that it incorporates two lamps located on a rotary device, so that at the time one lamp would give out a control circuit would be closed automatically, actuating the device and swinging the second lamp into position.

United Air Lines has felt for some time that the use of a sealed-beam-type landing light would afford some major benefit and have suggested this to the Civil Aeronautics Authority for further study. At the present time with the normal filament and parabolic reflector it is difficult to obtain a sharp cutoff or channel of light, as there is considerable dispersion around the outside of the beam of light. Channeling could be accomplished, of course, by the means of a long cylinder projecting forward from the landing light, but this is impractical. The engineering section of United Air Lines has conducted some tests using a grid close to the lens of the light itself, with the grid surface blackened to prevent reflection and thus limit the dispersion. The grid used in this manner channels the light so that the beam itself has a sharp cutoff and projects directly to the place to be illuminated. There are cases, however, where dispersed light or a general over-all effect may be desirable. By utilizing the sealed-beam principle the two filaments could be placed in the landing light where one could be used with a grid or some similar unit for positive channeling, and the other used as a dispersed light. These could be controlled individually from the cockpit so that the pilot could choose between a sharp channeled light for both landing lights or a dispersed one, or could have one landing light with the positive channel beam and the other with a dispersed light.

Intensity of illumination of the present landing lights probably has been adequate in the past. However, with increased operation both in terms of volume and number of aircraft coming into an airport, and with the possibility of improved landing equipment permitting operation in more inclement weather, considerable comment has been expressed as to the need of landing lights with greater intensity. The author cannot

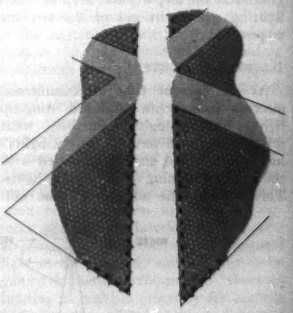

Figure 4. Positive ribbon lighting for airport runway

agree with this statement in its entirety. Discussions with many pilots have indicated that the need for additional illumination for the landing operation is required simply because there is a lack of adequate illumination on the ground. Therefore, it appears that a better solution would be found by completely lighting up the runway so that it glowed as a ribbon with no reflections. The general characteristics of the landing lights with respect to intensity, then, could remain as they are at the present. See Figure 4. This would eliminate the need of carry-

ing added weight in the form of additional electric power and larger landing lights aboard the aircraft.

Rotating-type landing lights or landing lights that may be swung fore and aft as the means of locating the light just where it is desired have been suggested and used. Although there may be some advantage in some special operations or conditions for such a light, it is believed there is one major disadvantage as compared to the stationary type. With the stationary landing lights, which are always in the same position with respect to the airplane, a pilot in landing can judge his distance above the ground and in effect get a rough measure of the attitude of his airplane to aid him in making the landing. With the rotatable light, unless it is stopped at the same place all of the time, he can establish no definite relationship between the light spot on the runway and the airplane.

Suggestions have been made that a taxi light, that is, a light essentially in the fuselage or in the wing that would illuminate objects on either side of the airplane would be desirable. One thought advanced was to incorporate additional elements in the main landing light which could be designed to act as a taxi light and could be controlled individually from the cockpit. Although in principle this may be a good idea, it still appears that the sounder approach would be to illuminate all of the objects on the ground at the airport, and keep as much lighting equipment out of the airplane as possible.

Navigation Lights

At the present time all commercial aircraft incorporate standard wing-tip lights and taillights. Further, what might have been termed "safety lights" have been added and incorporated with the existing running or navigation lights. This includes the addition of one taillight, one belly light, and one top light. All of these lights are actuated with a mechanism which causes them to flash on and off at frequent intervals. They were installed primarily for the purpose of identity and recognition in order to avoid possible collisions, and, although they have been fraternally referred to as "Christmas-tree" lights, it is the opinion of the author that they serve a very definite useful purpose and contribute considerably to the safety of night flying. Reference to Figure 5 shows the general characteristics of the running lights on the average commercial transport.

The actual value of the flashing lights is to avoid collision, and their real use comes in contact flying and slight overcast conditions, particularly in a heavily trafficked area about an airport. In instrument weather aircraft normally are controlled at greater distances from each other, and the flashing lights are not so much needed then. Actually no equipment is available to make such lights capable of penetrating overcast conditions.

The wing-tip lights give satisfactory identification for an airplane when one is approaching it from the front. At present, however, they do not give very good coverage to the three quarters rear. This is a condition that warrants improvement. Flashing taillights, however, do give a very reasonable indication of the presence of an aircraft to any one approaching from behind. One suggestion has been made, however, that, if a standard spacing were made between the white light and the red light on the tail, by constant use pilots soon would become accustomed to judging the distance they were away from an airplane by the apparent relationship of the two lights; that is, if the lights appeared to be very close together, they would know they were a far distance apart; and, contrary, if the lights were a considerable distance apart, they would know they were close upon the heels of another craft. This may have an advantage in formation flying, but it does not appear that approach and landing operations would be scheduled so closely as to warrant such an installation. In addition the use of single, twin, and triple rudders might confuse the establishment of a reasonably standard distance between lights.

One objection to the flashing lights has been the effect in mist or overcast. When the airplane is being operated in an overcast condition with the belly and top lights flashing, there is intermittent light and darkness in the cockpit and cabin, due to the reflection of the flashing light on the overcast. This, of course, is not all that might be desired. Some scheme similar to that shown in Figure 6 might be adopted. Elimination of the belly and top lights and redesign of tip lights and taillights with the flashing principle still retained would give adequate coverage, so that the lights could be seen from all angles by approaching aircraft, and yet would keep the glow effect in an overcast condition far enough away so that it would not affect too greatly the cabin or cockpit.

Cockpit

Lighting of the cockpit may be considered under two major classifications.

General or Ground Check

There is a general need for over-all illumination of the cockpit primarily for use in checking the controls and the instruments prior to takeoff and after landing. There may be some use for general over-all lighting in en-route operation, but it is infrequent, and its prime use will be prior to actual flight. It is important that the installation of over-all lighting satisfy the full sense of the definition, that is, illuminate ade-

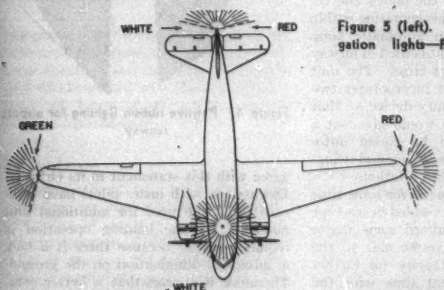

Figure 5 (left). Present navigation lights—flashing type

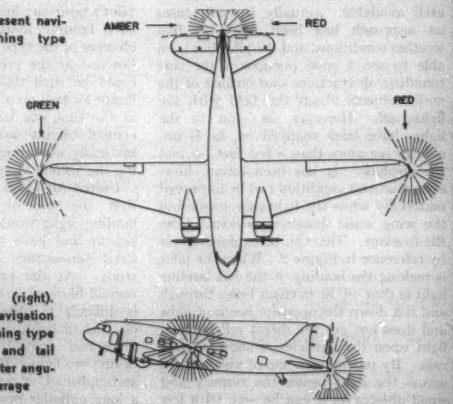

Figure 6 (right). Proposed navigation lights—flashing type with wing and tail having greater angular coverage

quately every portion of the cockpit where any controls, knobs, dials, instruments, or equipment of similar nature are located. Present cockpits have lights located at various points which, although they may give adequate light within a short distance of the source, do not give the necessary amount of light to another section of the cockpit that might well justify a minute inspection prior to operation of the aircraft. Further, there is a certain amount of paper work in the form of charts, records, and logs which the crew must fill in or refer to, and adequate light must be available for this purpose.

EN-ROUTE OPERATION

In en-route operation there are two considerations, namely:

(*a*). Adequate lighting of the instruments at all times.

(*b*). Auxiliary or spot lighting for the purpose of recording data, reading charts, or plotting of the course by either the pilot or copilot.

With respect to instrument lighting, it is very definitely desired that some form of indirect lighting of the instruments be accomplished. At present, with the dimming type of partial over-all lights which throw the light directly on several instruments the degree of illumination is not the same for each particular instrument. This is undesirable, because some of the instruments then become easier to read than others. It is essential that all instruments be lighted to the same degree and that the intensity can be

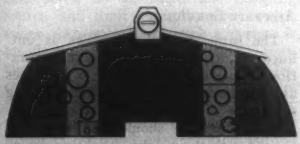

Figure 7. Average lighting relationship of existing instrument panels

changed by means of a suitable rheostat control to either "full off" or "full on," or, to any desired degree of illumination between the two extreme points. Figure 7 shows a tone relationship or an illumination relationship between instrument lighting in an existing transport cockpit. Figure 8 shows what is desired. It is appreciated that the use of individual instrument lighting by means of direct methods adds considerable complication to the electric system in the cockpit, and service experience to date has not been very good on the individual elements of such installations. However, it is believed that in principle this method is sound and that efforts to accomplish these desired results should not be relaxed.

One of the objections to the partial type of over-all lights which have been used for lighting the instrument panel has been the bad reflection on the instrument-panel glass, and on the cockpit windshield as well. Tests conducted using a special coating on instrument glasses and on the windshield have indicated that this condition is well along toward being corrected. Such an improvement would eliminate one of the objections of partial over-all lighting of the instruments.

At the present time many commercial cockpits are equipped with an auxiliary source of light such as a spotlight. This light is for the purpose of controlling a spot of light for use by either the pilot or copilot, so that accurate reading of charts, plotting of course, or other necessary paper work can be accomplished. This may be done either by the pilot or

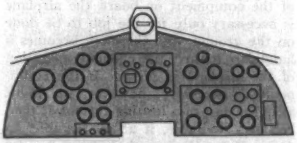

Figure 8. Desired even lighting relationship of instrument panel

copilot and should be so designed that it does not interfere with the other's vision in flying the craft. It appears relatively simple to shield the source of light so that it does not attract the attention of the crew member not using it, but no satisfactory means has yet been found for controlling the illumination of the cockpit or glare caused by the reflection of the spotlight on the light-colored charts or papers being studied or analyzed.

In order to eliminate some of these difficulties of spot lighting as well as to improve over-all cockpit lighting, considerable study has been made with the use of fluorescent lights. This may offer very definite advantages and spot sources of ultraviolet perhaps can be used for lighting charts and records, outlined or drawn with fluorescent active material. Some experiments have indicated that this may give adequate legibility to the charts or course maps and still not cause undesirable illumination for the member of the cockpit crew who is not using the chart. It is also believed that by intelligent positioning of the spotlights they could serve a dual purpose of giving both adequate over-all light when desired and the ultraviolet spot as needed. This can be accomplished simply by using an ultraviolet filter (as already has been accomplished in many places) in conjunction with the main source of light. Such a scheme offers the optional use of full lighting or a control spot lighting.

Still another problem in this consideration of cockpit lighting has been that of having satisfactory illumination within the cockpit and still not adversely affecting vision outside of the cockpit during night operation. At the present during night operation and even with the cockpit instrument lights at a low level so that just the indications are discernible, it still takes the pilot a short time to acclimatize his eyes that he can have adequate night vision when looking out of the cockpit. Many studies are being made at the present in an effort to improve this situation such as the use of red light which will give good illumination to the instruments themselves and still not affect the so-called night vision, thus permitting the pilot to see equally well inside the cockpit and outside of the cockpit.

Although present experiments using ultraviolet light for activating fluorescent materials or instruments have not proved entirely successful to date, this may offer a means of obtaining adequately lighted instruments without the need of complicated indirect-lighting means for each individual instrument. It must be borne in mind, however, that it is very desirable to be able to change the degree of brilliancy of the instrument lighting dependent upon the particular conditions en route.

Cabin

Although passenger-cabin lighting has improved considerably over that in the past, much of the same problem still exists as in the cockpit lighting, and that is the matter of getting the available light in the right places and eliminating undesirable glare. With overhead lighting or what has sometimes been referred to as dome lighting, bright source spots can be reduced materially and probably can be eliminated altogether by the use of indirect or alcove lights. This is very definitely desirable. The main light in the cabin is then dependent upon reflection from light-colored surfaces in the cabin interior. This is also advantageous from the point of adequate light in the daytime, and much is to be gained from this arrangement. Over-all lighting at night is primarily for loading and unloading of passengers and ground operation and has a value at the start of the flight to permit the stewardesses and passengers to get generally settled before the beginning of the flight. In addition it is necessary when meals are being served.

In a day airplane or sleeper airplane, particularly when the latter does not have full partitions, some of the passengers may desire to sleep while others may desire to read or talk with one another. Some means of auxiliary or spot lighting, which we have called reading lights in the past, is necessary. One of the biggest objections has been that both the source of light and the projection of light to the paper or book being

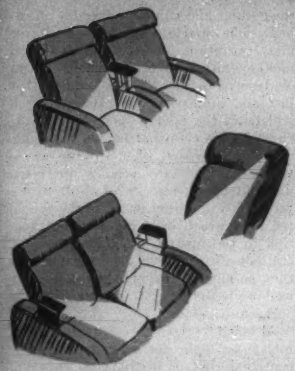

Figure 9. Possibilities for reading lights

read cause undesirable reflections to the individual not using the light. Another objection has been that the positioning of the source of light has not always been made so as to give the most efficient utilization of it for the person who wishes to use it.

Some suggestions as to possibilities with auxiliary or reading lights in the cabin are shown in Figure 9. It is appreciated that any one of these suggestions does not solve all of the difficulties. However, it should be pointed out that passenger business is still to be an important source of revenue of the air-transport companies for some time to come, and an intelligent solution to this problem is definitely needed.

An additional type of lighting required in the cabin is that for servicing, or, stated in another manner, the furnishing of additional light at the crew attendant's quarters so that the attendant's work can be accomplished properly. Use of lights in some present commercial transports, although properly shielded at the light source, have still been so located that they have permitted a considerable amount of reflection, which has the effect of indirectly lighting a good portion of the cabin close to the service quarters. This has proved very undesirable to those people who are seated close to the service quarters. It is appreciated that this problem is further complicated, because usually at service quarters light-covered shiny surfaced materials are used. It is believed, however, that attention again should be paid to the use of over-all or indirect lighting in the service quarters when the entire section is being used for the serving of food or handling of equipment. A separate source for auxiliary or spot lighting should be provided for the use of the attendant to accomplish paper work or other jobs that do not require the full utilization of the service quarters.

It is realized that as airplanes become larger separate quarters both for passenger lounges and the service section probably will be used, segregating them entirely by means of partitions. This will aid in keeping light from disturbing other passengers. It is believed, however, that the same general principles still apply.

Ground Servicing

Loading and Unloading—Passengers and Cargo

It is believed that in general a sound principle of aircraft design is to develop the airplane to be a self-sufficient unit independent as much as possible of ground equipment. There are several places, however, where it is desirable to make exceptions to this rule, particularly where the weight or complication of the equipment on board the airplane is necessary only for the job to be done on the ground, and therefore becomes a handicap toward the efficient operation of the airplane in flight. If the equipment is necessary, however, for flight as in the case of a heating system, it then becomes desirable, if at all possible, to design the system so that it can handle the ground problems adequately.

In the case of lighting, however, for loading and unloading of passengers and cargo, this does not hold true for the operation performed outside of the airplane. If the cabin is lighted adequately for operation in flight, there is no need for special lights being installed in or at the airplane door which would be used for the purpose of lighting the platform of the loading stand. This latter type of light is used only when passengers are getting on and off the airplane and undoubtedly would have no use while en route. Therefore, it is more practical to put the light itself on the passenger loading stand. Spotlights or small floods (which have been suggested), placed in the door or lower portion of the door jamb of the airplane and utilized only at the time of loading and unloading passengers, are unsatisfactory, and a finer job can be done when the same lights are built into the loading stand.

The same principle applies with respect to loading and unloading cargo from the door of the airplane to the loading equipment. The light should be placed on the loading equipment, not in the door of the airplane or on the door jamb. However, it is definitely necessary and desirable that adequate light be provided within the cargo compartment of the airplane itself, as this is necessary to permit proper stowing of cargo. Also to identify and read waybills on individual shipments. Such lighting cannot be accomplished satisfactorily from an outside ground source, and can best be done by design within the airplane. One point of interest here is that on passenger loading and unloading equipment, lights should

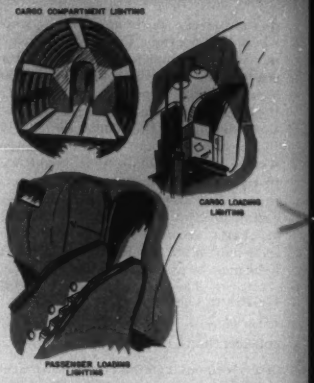

Figure 10. Cargo-compartment lighting, cargo-loading lighting, and passenger-loading lighting

be so low as to light the path adequately and yet not have the passenger's shadow block the vision of steps and ground or loading ramp obstructions. In cargo loading and unloading equipment, and in the cargo compartments themselves, it is desirable that the light source be both high and low, that is, in the form of flood or indirect lighting, so that adequate light will be available so that all obstructions, steps, and so forth, can be seen, in addition to giving adequate light at any height for the proper handling and stowing of cargo. See Figure 10.

Aircraft Servicing

The same general principles as outlined for loading and unloading operations apply to the servicing of airplanes at the terminal station. The lighting should be accomplished on the ground, and the airplane should not be handicapped with the weight of lighting equipment to satisfy the ground operation. It is believed that one of the best methods is to incorporate low-powered floodlights which in effect would "bathe" with a relatively low illumination those portions of the airplane normally requiring service. This would be adequate for inspection and simple servicing procedures, but not bright enough to cause glare or make working about the craft difficult. It is further believed that these lights should be of a lower intensity than the lighting required for cargo-handling equipment.

It has been suggested that these lights be of the flush type built directly into the ramp or apron about the terminal. Although this is most desirable from a functional or operating point of view, it is appreciated that there are many problems, such as adequate sealing, that must be overcome. The principle, however, is considered as being worthy of further study.

Damping Effect of D-C Marine Propulsion Motors on Vibrations Produced in Drive Shafts by Large Propellers

BERNARD LITMAN
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Synopsis: D-c machines often are employed in ship-propulsion drives where maneuverability and a wide speed range are required. The d-c machine also has the advantage of serving as a source of damping if propeller pulsation should coincide with the natural frequency at some speed. This damping force arises because of the fact that any change in speed of the motor will cause a corresponding change in load current and torque. This torque change acts to oppose the original speed change, thus providing an effective damping force. The necessary equations and circuits are developed for calculating this damping effect and an illustrative calculation is included with actual test values for comparison.

IT IS occasionally necessary to determine the magnitude of torsional vibration in a system running at one of its critical speeds. To do so requires a knowledge of all the damping sources within the system and their magnitudes. Typical damping sources are hysteresis damping in the shaft and friction and viscous damping in the system. If the system includes a d-c machine, this will also serve as an important damping source and limit the vibration magnitudes. An example of such a system is an electric ship-propulsion drive. Here the d-c machine is frequently used because of its ease of speed control over a wide range. However, operation may occur at the natural frequency, where propeller vibrations may set up abnormal stresses in the shafting. If investigation shows the damping to be large enough, the necessity of changing the natural frequency by an uneconomical redesign of the mass-elastic system may be avoided.

The damping force in a d-c machine is similar in behavior to a viscous damping force, being proportional to the speed, though the origin of this force is somewhat different. Assume, for example, that the speed of the machine has dropped below its mean value at some point of its vibration cycle. This causes a corresponding drop in the countervoltage of the motor so that a larger load current will tend to flow. This load current and the corresponding load torque will tend to speed up the motor, thus opposing the drop in speed which we have assumed. If we neglect the inductance of the armature circuit and consider only the resistance, then torque changes will be in phase with and proportional to speed changes, so that these torque changes act as a true damping torque. When the inductance of the armature circuit is considered, we no longer have pure damping since the current and torque changes are not in phase with the speed variation. Thus, during part of the cycle the damping torque may actually aid the oscillation while during the rest of the cycle it opposes the oscillation. The vibrational energy imparted by the propeller is absorbed partly by the propeller itself as in any case of viscous damping. The remainder of the energy is absorbed by the motor by means of the mechanism described above. The magnitude of vibration in the different parts of the system will rise to the point where the energy absorbed is equal to the energy imparted by the propeller.

Actual solutions are most simply made by setting up equivalent electrical circuits which have the same differential equations as the mechanical system we are considering. The source of pulsating torque becomes an applied voltage at some point in the system. Shaft elements become capacitors, masses become inductances, and damping elements become resistances. When the inductance of the armature circuit is included, our equivalent circuit becomes somewhat more elaborate, containing negative resistance and inductance terms.

The standard electrical symbols for these elements are used in the figures which follow. These circuits are solved by using the standard methods of complex algebra as for any steady-state a-c network. The circuit may be solved for any operating speed by using the corresponding value of the applied pulsating frequency. The maximum values of shaft torque are most conveniently determined by first finding the natural speeds with damping neglected. These will be very near the speeds at which maximum torques occur when damping is considered. For a more accurate calculation, one or two other speeds near this natural speed may be checked and a curve drawn through these points so as to estimate the peak.

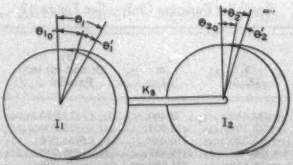

Figure 1. Physical system of two masses and connecting shaft

The Two-Mass System Without Damping

Refer to Figure 1 for which the following symbols apply:

θ_1 = actual angular position of rotor—radians

θ_{1_0} = uniformly moving angular vector which would be the position of the rotor if there were no torque pulsations and the rotor moved uniformly

$\theta_1' = \theta_1 - \theta_{1_0}$ = rotor displacement above or below mean position

Similarly for θ_2.

I_1 = moment of inertia—pound-feet squared divided by g

Similarly for I_2.

K_s = shaft spring constant—foot-pounds per radian

The natural frequency of this system will then be given by

$$f = \frac{1}{2\pi}\sqrt{K_s\left(\frac{1}{I_1}+\frac{1}{I_2}\right)} \qquad (1)$$

This familiar result may be obtained from the differential equations or the equivalent circuit which we give now. In order to determine the effect of torque variations, we shall assume the second mass to be absorbing the torque transmitted from the first but doing so nonuniformly by having a mean torque T_0 and a smaller superimposed sinusoidal

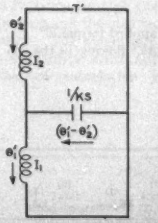

Figure 2a (left). Equivalent electric circuit for two-mass system without damping

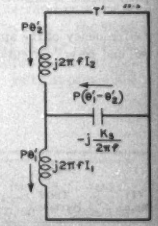

Figure 2b (right). Equivalent circuit with proper values of admittance and susceptance at frequency F

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torque T' (hence total torque $T = T_0 + T'$), while the first mass has supplied to it a constant torque T_0.

Let p represent the differential operator $\frac{d}{dt}$. Taking torques applied to the first mass, we have:

$$T_0 - K_s(\theta_1 - \theta_2) = I_1 p^2 \theta_1 \quad (2)$$

For the second mass

$$K_s(\theta_1 - \theta_2) - T = I_2 p^2 \theta_2 \quad (3)$$

If our absorbed torque were not pulsating and the motion were uniform, these equations would reduce to

$$T_0 - K_s(\theta_{1_0} - \theta_{2_0}) = 0 \quad (4)$$

$$K_s(\theta_{1_0} - \theta_{2_0}) - T_0 = 0 \quad (5)$$

By subtraction of these from the first set of equations, we have

$$I_1 p^2 \theta_1' + K_s(\theta_1' - \theta_2') = 0 \quad (6)$$

$$I_2 p^2 \theta_2' - K_s(\theta_1' - \theta_2') + T' = 0 \quad (7)$$

where the primed quantities are angle and torque variations above (or below) mean value. It is these quantities in which we are interested since they represent oscillations or displacements from the mean position.

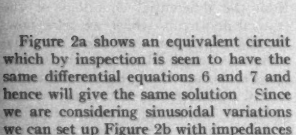

Figure 3. Equivalent circuit for two-mass system with motor resistance damping in one mass

Figure 2a shows an equivalent circuit which by inspection is seen to have the same differential equations 6 and 7 and hence will give the same solution. Since we are considering sinusoidal variations we can set up Figure 2b with impedances and find the response by using the complex vector notation.

f = frequency of the applied torque T'

$p\theta_1$ and $p\theta_2$ = "currents" flowing in the circuit

If T' is the maximum torque variation, then the "voltage" across the capacitor is the maximum value of $K_s(\theta_1 - \theta_2)$ or the maximum value of shaft torque. If T' is expressed in per unit (that is, as a fractional part of the mean torque, T_0), then the shaft torque will likewise be in per unit. Thus if we obtain a value of 0.5 for shaft-torque variation, the actual maximum shaft torque (and stress) will be 1.5 times the normal design value.

From Figure 2b it is seen that the total impedance is

$$\frac{1}{\frac{1}{j2\pi f I_1} + \frac{2\pi f}{jK_s}} + j2\pi f I_2$$

which will equal zero when the frequency is given by

$$f = \frac{1}{2\pi}\sqrt{K_s\left(\frac{1}{I_1} + \frac{1}{I_2}\right)}$$

This verifies equation 1.

It is evident at resonance that the magnitude of the oscillation is infinitely large; hence we must include damping to obtain the true behavior of the system.

Inclusion of Resistive Damping

When we include resistive damping we must consider the variation of electrical torque within the machines—hence we add another set of differential equations to our previous set. With reference to Figure 1, we have for body number 1:

$$K_1\phi_1 i_1 - K_s(\theta_1 - \theta_2) = I_1 p^2 \theta_1 \quad (8)$$

$$E_1 = i_1 R_1 + K_{c1}\phi_1 p\theta_1 \quad (9)$$

where

$K_1\phi_1$ = motor-torque constant in pound-feet per ampere

$K_{c1}\phi_1$ = motor counterelectromotive force constant in volts per radian per second

E_1 = applied line voltage to machine number 1 in volts

R_1 = machine-armature-circuit resistance in ohms

i_1 = machine-armature-circuit current in amperes

We may write again the equations for uniform (nonpulsating) motion, and obtain

$$K_1\phi_1 i_{1_0} - K_s(\theta_{1_0} - \theta_{2_0}) = 0 \quad (10)$$

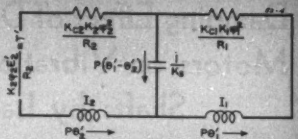

Figure 4. Equivalent circuit for two-mass system with motor resistance damping in both masses

$$E_1 = i_{1_0} R_1 + K_{c1}\phi_1 p\theta_{1_0} \quad (11)$$

and by subtraction we obtain equations in terms of the variation from mean values:

$$K_1\phi_1 i_1' - K_s(\theta_1' - \theta_2') = I_1 p^2 \theta_1' \quad (12)$$

$$i_1' R_1 + K_{c1}\phi_1 p\theta_1' = 0 \quad (13)$$

We may eliminate i_1' from equations 12 and 13 and obtain

$$\frac{-K_1\phi_1 K_{c1}\phi_1 p\theta_1'}{R_1} - K_s(\theta_1' - \theta_2') = I_1 p^2 \theta_1' \quad (14)$$

For the second machine we assume the torque absorbed, $K_2\phi_2 i_2$, is made up of a mean torque $K_2\phi_2 i_{2_0}$ and a sinusoidally varying torque $K_2\phi_2 I_2'$ (which is the same as T' given in the previous section); and that this pulsating load being absorbed by the second machine causes the pulsations which we are considering. We therefore may write for the second motor:

$$K_s(\theta_1 - \theta_2) - K_2\phi_2 i_2 = I_2 p^2 \theta_2 \quad (15)$$

and under nonpulsating conditions we have:

$$K_s(\theta_{1_0} - \theta_{2_0}) - K_2\phi_2 i_{2_0} = 0 \quad (16)$$

Hence by subtraction, we obtain:

$$K_s(\theta_1' - \theta_2') - K_2\phi_2 i_2' = I_2 p^2 \theta_2' \quad (17)$$

Since we assume that i_2' is a known load-current variation, we may replace $K_2\phi_2 i_2'$ by a known torque variation T' and we may now set up the equivalent circuit of Figure 3 whose differential equations are seen to be the same as equations 14 and 17.

As before, for a given frequency we may insert a complex impedance, and solve for the "voltage" or torque across the "capacitance" or shaft in terms of the pulsating applied torque T'. We notice

Table I

Propeller Damping Only—See Figure 13

(1) Rpm	(2) ∞ Third Harmonic	(3) $3K_{\phi_1\phi_2}$	(4) $j\omega I_p$	(5) $-jK_s/\omega$	(6) $j\omega I_m$	(7) (5) and (6) in Parallel	(8) Total Impedance	(9) (7)/(8) Magnitude Only	(10) (9) times (Rpm/250)³
100	31.4	770	$j14,030$	$-j34,650$	$j8,400$	$j11,220$	$770+j25,250$	0.495	0.071
150	47.2	1,154	$j21,100$	$-j23,100$	$j12,700$	$j28,200$	$1,154+j49,300$	0.573	0.206
200	62.8	1,540	$j28,000$	$-j17,320$	$j16,900$	$j650,000$	$1,540+j678,000$	0.960	0.612
230	72.4	1,770	$j32,300$	$-j15,050$	$j19,480$	$-j66,000$	$1,770-j33,700$	1.950	1.650
250	78.6	1,925	$j35,100$	$-j13,850$	$j21,160$	$-j40,000$	$1,925-j4,900$	7.61	7.81
256	80.5	1,970	$j35,900$	$-j13,540$	$j21,660$	$-j36,100$	$1,970-j200$	18.20	19.
275	86.5	2,115	$j38,800$	$-j12,600$	$j23,300$	$-j27,400$	$2,115+j11,300$	2.40	2.9.

that our circuit now has a resistance term which, as might be expected, varies inversely as the actual armature resistance R_1. Thus with a smaller armature resistance, a given speed change will result in a larger load current and torque variation so that the resistance damping term in our circuit must increase.

One might ask why the damping term appears only in the branch of the circuit pertaining to machine number 1 and why there is not a similar term for machine number 2. The answer lies in the fact that we are assuming the load-current variation i_2', to have a known value. Actually this quantity would be difficult to determine without actual measurement since it depends not only upon the nature of the pulsating load but also upon the characteristics of machine number 2 which is supplying this load. We, therefore, may carry our analysis a step further by assuming that it is the line voltage E_2 whose variation is known and that the load current I_2 does not vary directly with E_2 because we must include the damping effects of motor number 2.

We can then write for machine number 2

$$K_{c2}\phi_{f2}p\theta_2 - i_2R_2 = E_2 \tag{18}$$

and in terms of the variation from mean values we obviously will have

$$K_{c2}\phi_{f2}p\theta_2' - i_1'R_2 = E_2' \tag{19}$$

We may now eliminate i_2' from equations 17 and 19 and obtain

$$K_3(\theta_1' - \theta_2') - \frac{K_m K_{f2}\phi_{f1}^2}{R_2}p\theta_2' - I_2p^2\theta_2' + \frac{K_{f2}\phi_{f2}E_2'}{R_2} = 0 \tag{20}$$

We may again set up an equivalent circuit from equations 14 and 20 and obtain Figure 4.

Now it is apparent that we have a resistance term in both branches of our circuit. This analysis might be carried further to the ultimate source of torque pulsations. Thus if the load being supplied by machine number 2 were a motor-driven air compressor, we might add another branch to our circuit to include the characteristics of the third machine and apply our pulsating torque from the air compressor to this branch. This more

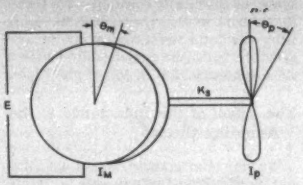

Figure 5. Physical system for ship-propulsion drive

complete circuit is not developed here since the damping features of d-c machines are more easily demonstrated with a simple circuit and the simpler circuits can usually be applied to most cases with a fair degree of accuracy.

If, as is the case in most systems, the torque pulsations are not sinusoidal, we may still resolve them into their harmonic components, treat each harmonic separately, and superimpose the responses to each harmonic torque pulsation in order to obtain the complete solution.

A Case of Combined Electrical and Mechanical Damping

Before including the effects of the inductance of the armature circuit we shall show how the simplified damping circuits already presented may be applied to a specific case which will be treated numerically in the appendix. This is the case of the ship-propulsion drive shown in Figure 5. The differential equations for the motor remain as before but we must also include the damping introduced by the propeller itself since its torque changes with speed changes.

The propeller torque under steady conditions varies nearly as the square of the speed. Assuming for the moment that this holds even when the speed is undergoing oscillations, we may write

Propeller torque $= K_p\omega_p^2$ pound-feet

where ω_p is given in radians per second. Then:

$$K_3(\theta_m - \theta_p) - K_p\omega_p^2 = I_p p^2\theta_p \tag{21}$$

and under nonoscillating conditions:

$$K_3(\theta_{m_0} - \theta_{p_0}) - K_p\omega_{p_0}^2 = 0 \tag{22}$$

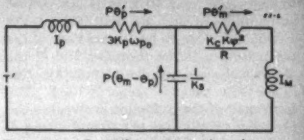

Figure 6. Equivalent circuit for ship-propulsion drive

Hence

$$K_3(\theta_m' - \theta_p') - K_p(\omega_p^2 - \omega_{p_0}^2) = I_p p^2\theta_p' \tag{23}$$

But

$$\omega_p^2 - \omega_{p_0}^2 = 2\omega_{p_0}(\omega_p - \omega_{p_0}) = 2\omega_{p_0}\omega_p' = 2\omega_{p_0}p\theta_p' \tag{24}$$

Hence

$$K_3(\theta_m' - \theta_p') - 2K_p\omega_{p_0}p\theta_p' = I_p p^2\theta_p' \tag{25}$$

Equation 25 has a damping term whose coefficient is $2K_p\omega_{p_0}$, but actually with the ship moving forward at constant speed, changes in angular speed of the propeller will cause larger changes in propeller torque than we have anticipated from the "square of the speed" law. Thus we can see that the propeller need not drop to zero speed in order to have zero torque, for if it drops sufficiently it will screw freely through the water without putting out any torque. Hence our damping term should be increased, the exact amount of the increase depending somewhat on the propeller design characteristics. A fairly close approximation, and the one which is generally used is to increase the damping by 50 per cent. Hence we may rewrite equation 25 thus:

$$K_3(\theta_m' - \theta_p') - 3K_p\omega_{p_0}p\theta_p' = I_p p^2\theta_p' \tag{26}$$

Combining this with the equation for the motor (see equation 14), we can set up an equivalent circuit which can be solved without difficulty for steady-state sinusoidal pulsations. This circuit is shown in Figure 6.

These torque pulsations arise because of the oscillating torque of the propeller as it passes through the varying wake of the ship and the obstructions of the stern frame. The magnitude of this pulsation is a quantity which is practically impossible of calculation but approximate

Table II

Propeller and Motor Resistance Damping—See Figure 14

(1) Rpm	(2) ω Third Harmonic	(3) $3K_p\omega_{p_0}$	(4) $j\omega I_p$	(5) $-jK_3/\omega$	(6) $j\omega I_m$ + Resistance	(7) (5) and (6) in Parallel	(8) Total Impedance	(9) Ratio, (7)/(8)	(10) (9) × (Rpm/250)²
100	31.4	770	$j14,030$	$-j34,650$	$11,100+j8,460$	$16,500+j4,200$	$17,370+j13,230$	0.670	0.108
150	47.2	1,154	$j21,100$	$-j23,100$	$11,100+j12,700$	$25,600+j850$	$26,754+j21,950$	0.740	0.266
200	62.8	1,540	$j28,000$	$-j17,320$	$11,100+j16,900$	$28,400-j17,100$	$29,940+j10,900$	1.040	0.665
230	72.4	1,770	$j32,300$	$-j15,050$	$11,100+j19,480$	$17,500-j22,000$	$19,370+j10,300$	1.290	1.09
250	78.6	1,925	$j35,100$	$-j13,850$	$11,100+j21,160$	$12,100-j21,800$	$14,025+j13,300$	1.29	1.29
266	80.5	1,970	$j35,900$	$-j13,540$	$11,100+j21,660$	$11,000-j21,300$	$12,970+j14,100$	1.27	1.33
275	86.5	2,115	$j38,600$	$-j12,600$	$11,100+j23,300$	$7,400-j19,800$	$9,818+j17,060$	1.08	1.30

figures from tests on models and actual ships indicate that we may assume the torque pulsation to be ten per cent of the mean torque of the propeller and in the absence of more definite information, this is the value that is commonly used. The frequency of the pulsation is N times the propeller revolutions per second where N is the number of blades in the propeller.

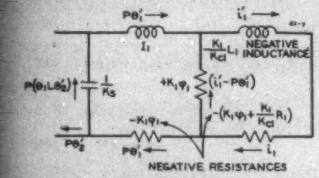

Figure 7. Equivalent circuit when motor inductance is included

Figure 6 tacitly assumes that the propulsion motor is connected to an infinite bus, whereas it is actually connected to a generator whose effects should be considered. This may be done in either of two ways:

1. Elaborate the equivalent circuit to include a branch for the generator.

2. Make an assumption that the internal generated voltage of the generator is constant.

This is very nearly true since from Figure 6 we see that the propeller damping term absorbs much of the vibration because it is directly in series with the torque pulsation, and the remaining pulsations in the motor circuit are reduced. Hence the speed oscillations which are transmitted to the generator are quite small and the internal generated voltage may be assumed as practically constant. We therefore should replace the term R_1 in Figure 6 by the total resistance of motor and generator armature circuits and we have a close approximation to actual conditions.

The Effect of the Inductance of the Armature Circuit

We may refer again to our two-machine system with inductance in each armature circuit being considered this time. This inductance is principally that of the machine itself but should also include that of the lines connecting it to the power supply. We assume as before that machine number 1 is on an infinite bus while machine number 2 is supplying a system whose line voltage E_2 is pulsating periodically.

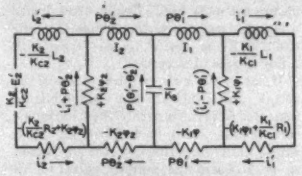

Figure 8. Complete circuit for two motors with inductance of both included

Considering machine number 1 first we may write our torque equation as before:

$$K_1\phi_1 i_1 - K_s(\theta_1 - \theta_2) = I_1 p^2\theta_1 \qquad (27)$$

Our voltage equation includes an inductive term, $-L\frac{di}{dt}$, and becomes:

$$E_1 = i_1 R_1 + K_{e1}\phi_1 p\theta_1 + L_1 p i_1 \qquad (28)$$

Under steady nonpulsating conditions, these equations will reduce to the same simpler expressions given in equations 10 and 11 and by subtraction we obtain equations in terms of the variation from mean values, thus:

$$K_1\phi_1 i_1' - K_s(\theta_1' - \theta_2') = I_1 p^2\theta_1' \qquad (29)$$

and

$$R_1 i_1' + K_{e1}\phi_1 p\theta_1' + L_1 p i_1' = 0 \qquad (30)$$

Equations 29 and 30 are sufficient for setting up an equivalent network but in order to do so we must first modify them somewhat by adding and subtracting certain terms and we thus obtain equations 31 and 32 which are seen to be the same as the first set of equations.

$$K_1\phi_1(i_1' - p\theta_1') - K_1\phi_1 p\theta_1' - K_s(\theta_1' - \theta_2') = I_1 p^2\theta_1' \qquad (31)$$

$$\left[K_1\phi_1 + \frac{K_1}{K_{e1}}R_1\right] i_1' + \frac{K_1}{K_{e1}} L_1 p i_1' - K_1\phi_1(i_1' - p\theta_1') = 0 \qquad (32)$$

These two equations can be set up into an equivalent circuit which is shown in Figure 7. Comparison of the circuit with equations 31 and 32 shows that the two agree.

The open end of this circuit will be tied on to a similar one for machine number 2. We see that this circuit is somewhat more elaborate than our previous circuits and has smaller damping because there are negative resistance terms as well as a negative inductive term; this latter being equivalent to a capacitance. If we let L_1 approach zero our circuit can be simplified and will reduce to our previous circuits with a single resistive term of magnitude $K_{e1}K_1\phi_1^2/R_1$ as before. On the other hand, if we let L_1 approach infinity it is seen that all our resistance terms drop out and we have a circuit with no damping at all.

For machine number 2 we will have a similar pair of equations except that the terms in the voltage equation will not be placed equal to zero but equal to E_2' which is the pulsation in the line voltage E_2. Thus we have:

$$E_2' = K_{e2}\phi_2 p\theta_2' - i_2' R_2 - L_2 p i_2' \qquad (33)$$

$$K_s(\theta_1' - \theta_2') - K_2\phi_2 i_2' = I_2 p^2\theta_2' \qquad (34)$$

These can then be expanded into equations similar to equations 31 and 32 so that an equivalent circuit may be set up. Figure 8 shows the complete equivalent simplified circuit.

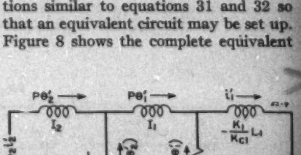

Figure 9. Equivalent circuit with damping considered in one motor only

Table III. Ship-Propulsion Drive—Tabulated Calculations

Inductive Case—See Figure 15

Rpm	ω Third Harmonic	$3K_{e\omega}\omega_2$	$j\omega I_2$	$-jK_s/\omega$	$j\omega I_m$	$-12.9-j\omega L$
100	31.4	770	$j14,030$	$-j34,650$	$j8,460$	$-12.9-j0.0202$
150	47.2	1,154	$j21,100$	$-j23,100$	$j12,700$	$-12.9-j0.0304$
200	62.8	1,540	$j28,000$	$-j17,320$	$j16,900$	$-12.9-j0.0404$
230	72.4	1,770	$j32,300$	$-j15,050$	$j19,480$	$-12.9-j0.0466$
250	78.6	1,925	$j35,100$	$-j13,850$	$j21,160$	$-12.9-j0.0507$
256	80.5	1,970	$j35,900$	$-j13,540$	$j21,660$	$-12.9-j0.0518$
264	83.0	2,035	$j37,000$	$-j13,120$	$j22,350$	$-12.9-j0.0539$
275	86.5	2,115	$j38,600$	$-j12,600$	$j23,300$	$-12.9-j0.0557$

Rpm	Unit A	Unit B	Unit C	Total Impedance	Unit C Total Impedance $\times\left(\frac{\text{Rpm}}{250}\right)^2$
100	$3,960-j5,300$	$3,947+j\ 3,160$	$4,720+j\ 2,890$	$5,490+j16,920$	0.31 0.05
150	$2,180-j4,400$	$2,167+j\ 8,300$	$5,150+j12,200$	$6,300+j33,300$	0.39 0.14
200	$1,355-j3,600$	$1,342+j13,300$	$22,500+j50,200$	$24,040+j76,200$	0.67 0.43
230	$1,110-j3,220$	$1,097+j16,260$	$93,000-j117,500$	$94,800-j85,200$	1.18 1.00
250	$910-j3,020$	$897+j18,140$	$9,050-j56,400$	$10,975-j31,300$	2.38 2.38
256	$870-j2,950$	$857+j18,710$	$5,700-j48,000$	$7,670-j12,100$	3.34 3.50
264	$810-j2,880$	$797+j19,470$	$3,500-j37,000$	$5,600-j0$	6.70 7.50
275	$760-j2,790$	$747+j20,510$	$1,870-j32,300$	$3,985+j10,400$	2.92 3.53

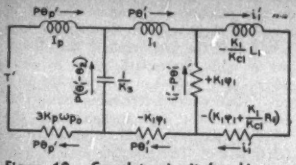

Figure 10. Complete circuit for ship-propulsion drive with motor inductance included

circuit including the branch we have already developed for machine number 1.

If for E_3' we use the maximum value of the line-voltage pulsation, then the "voltage" across the capacitor will be the maximum value of $K_3(\theta_1'-\theta_3')$ which is the maximum value of shaft torque. Similarly, we can determine the amount of load-current variation in both machines.

Other Cases With Inductance Included

From Figure 8 we see that at higher frequencies the armature-circuit inductance will reduce the damping but the load-current pulsation, i_3', will also be reduced since it must pass through an inductance. If we wish, we may assume that it is the load current i_3' and hence the pulsating torque applied to machine number 2 which remains constant while frequency changes. Such an assumption would enable us to see more clearly how the damping becomes less effective at higher frequencies. The circuit for this case is shown in Figure 9.

We may also set up an equivalent circuit for cases of combined electrical and mechanical damping as in the ship-propulsion drive which was treated by means of the simpler circuit, considering armature resistance only. By now it is apparent what form this circuit will take without rewriting all the differential equations and this circuit is shown in Figure 10. This circuit will be used in the appendix for the sample calculation of an actual system.

Determination of Machine Constants

A. Shaft Spring Constant K_s in Foot-Pounds Per Radian

For unit torque of one foot-pound the angular twist in radians of a shaft section is given by

$$\theta=\frac{32\times12\times L}{E_s d^4} \tag{35}$$

L = Length of section—inches
d = Diameter of section—inches
E_s = Shear modulus of elasticity—pounds per square inch

For steel shafting this may be rewritten:

$\theta=1.036\times10^{-6}L/d^4$ radian per foot-pound (36)

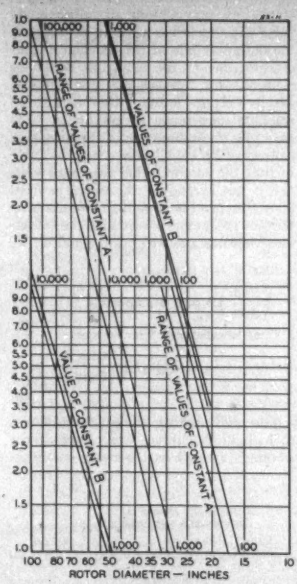

Figure 11. Standard values of WR^2 for d-c machines

$WR^2=A+B'l$ in pound-feet squared
l = Rotor core length in inches

With a number of shaft sections of different diameter and length, the formula is applied to each in turn and the summation $\Sigma\theta$ obtained. Then $K_s=1/\Sigma\theta$ in foot-pounds per radian.

B. Moment of Inertia I

The usual electric machine can be broken down into a number of cylindrical sections such as: coils, core, spider hub, spider arms, end plates, commutator bars, commutator V-rings. The moment of inertia of any such section may be calculated if the detail weights and dimensions are known. Note that the WR^2 must be divided by g (32.2 feet per second per second) in order to obtain moment of inertia I as used in the preceding equations.

In the absence of detail drawings of the machine a fairly close approximation to the WR^2 may be obtained from a knowledge of the rotor diameter and core length. This is due to the fact that for a given frame size, economical designs generally lead to approximately the same proportions for the various parts of the machine.

For a given rotor diameter the WR^2 varies directly with the core length so that we may write:

$$WR^2=A+BL \tag{37}$$

where A is the WR^2 for zero length and is due to the end plates, end winding, commutator, and so forth and B is the additional WR^2 per inch of core length. Both A and B are functions of the rotor diameter, varying approximately as the cube of the diameter so that we may draw a straight-line curve on logarithmic paper. This has been done in Figure 11 where the variation is shown for a wide range of standard d-c machines. For any given frame size the maximum and minimum WR^2 values differ by about ±8 per cent from the mean value, which is not too large a range for approximate calculations.

C. Motor-Torque Constant K_ϕ in Pound-Feet Per Ampere

This may be obtained from the nameplate rating of the machine and is given by:

$$K_\phi=\frac{\text{horsepower}}{\text{rpm}}\times\frac{5{,}250}{I} \tag{38}$$

where I is rated armature current in amperes.

If the machine is not operating at rated conditions, the actual operating conditions should be substituted in the equation. This constant is proportional to the field flux and will vary inversely as the speed if field control is used but will remain constant if armature-voltage control of speed is used.

D. Motor Counterelectromotive Force Constant $K_{e\phi}$ in Volts Per Radian Per Second

This likewise is obtained from the name-plate rating and is given by

$$K_{e\phi}=\frac{E\times60}{\text{Rpm}\times2\pi} \tag{39}$$

where E is the counterelectromotive force of the machine. This may be taken

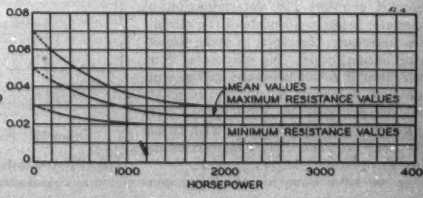

Figure 12. Standard values of armature-circuit resistance for d-c machines

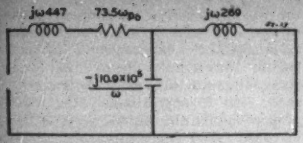

Figure 13. Numerical circuit values

Propeller damping only

as practically equal to the line voltage or for greater accuracy it may be corrected for IR drop. As with the torque constant, the counter electromotive force constant is proportional to the field flux.

E. Resistance of Motor-Armature Circuit R in Ohms

This may be determined from a knowledge of the conductor size, total conductor length, and number of parallel paths in the armature and in the series, commutating, and compensating field windings. The resistance of the connecting power lines may also be included but in most cases where all the equipment is located in physical proximity, the resistance of the lines is not large.

Where the design details are not available, an approximate estimate of the resistance may be obtained by comparison with standard machines. Economical designs require that the resistance loss be as small as possible and yet that the amount of copper used not be excessively large. Hence the per cent I^2R loss which is the same as the per cent voltage drop ($I^2R/IE = IR/E$) has roughly a constant value for a given-size machine. These values are plotted in Figure 12 for a wide range of machines and enable the determination of the resistance as:

$$R = CE/I \text{ ohms}$$

where C is obtained from the curve of Figure 12 and E and I are taken from the name-plate reading.

When more accurate calculations are desired, the actual resistance of the machine should be obtained, since the magnitude of the damping depends principally on the value of the resistance which is used.

Inductance of the Armature Circuit L in Henrys

The inductance of the armature circuit is not capable of accurate calculation since it requires the determination of magnetic fields in all parts of the circuit. It is necessary, therefore, to make simplifying assumptions. We may note, however, that it is not necessary to have inductance values as accurately as resistance values since the inductance enters as a secondary term when we wish to use the more accurate circuit instead of the simpler resistance damping circuit.

As we have done for the other constants, we may obtain an approximate value of inductance without knowing all the design details of the machine. This is again due to the fact that detail dimensions for a given-size machine fall within certain limits, thus fixing the machine inductance within limits. For example, the inductance of the armature coils must be kept below a certain value so that the commutating reactance voltage is not excessive. Assuming a fixed allowable reactance voltage, we may determine the factors upon which the inductance depends and we obtain equation 40.

$$L = \frac{100 \times \text{volts}}{\left(\frac{\text{Rpm}}{100}\right)^3 \times \text{poles} \times \text{amperes} \times \text{inches diameter} \times \text{inches core length} \times \left(\frac{\text{poles}}{\text{circuits}}\right)} \text{ henrys} \qquad (40)$$

The multiplier of 100 has been chosen to include the inductance of the stator windings as well as the rotor windings.

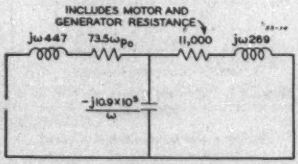

Figure 14. Numerical circuit values

Propeller and motor-resistance damping

This formula involves constants which may be taken from the name-plate reading and a knowledge of the rotor diameter and length. Comparison with more accurate calculations and with measurements indicates a fair agreement, and the error to be expected is generally less than 20 per cent.

Conclusions

Methods have been presented for determining the amount of damping present in d-c machines. From a number of cases which have been investigated, it is found that the magnitude of this damping is quite appreciable even in cases where other sources of damping are present. Methods for determining the various constants have been included and the work of calculation will be found to be fairly short. The problem presented in the appendix includes calculations for several assumptions and a range of speeds, whereas only one operating point (at the critical speed) need actually be calculated.

The question arises as to whether it is necessary to utilize the more elaborate inductive circuit. Usually it will be necessary to do so since it makes an appreciable difference in the results. A rough criterion which may be used is as follows:

Take the reactance voltage due to the armature inductance L, at the critical frequency F, and full-load current I. If this is less than three per cent of the rated machine voltage the simplified circuit may be used with fair accuracy. If it is any larger, the more elaborate circuit must be used in order to obtain satisfactory results.

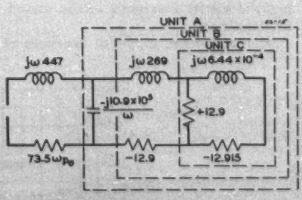

Figure 15. Numerical circuit values

Propeller and motor damping with motor inductance included

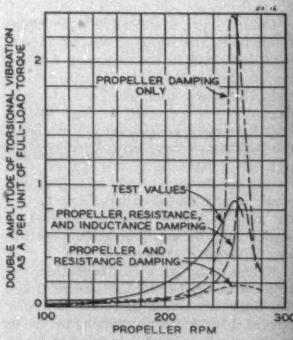

Figure 16. Comparative plot of calculated and test values of vibration amplitude, ship-propulsion drive

In order to determine the relative damping contribution of the propeller and the propulsion motor for an actual installation, sample calculations are presented in the appendix for such an installation. This drive was on board the Coast Guard cutter *Naugatuck* and oscillographic records of electrical and mechanical pulsations were taken. Torque pulsations in the shaft were recorded with a torsional strain gauge mounted on a calibrated section of the drive shaft. The cutter is driven by a single-screw three-bladed propeller. The motor is a 500-volt d-c machine rated 800 horsepower at 250 rpm and is powered by two 400-kw generators.

It is apparent from the comparative

Speed-Control System for an Aircraft Cabin-Supercharger Drive

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Synopsis: Cabin supercharging is becoming extremely important as flight ceilings for military aircraft are extended upward. Many different schemes have been worked out for using main-engine power to drive variable-speed blowers at speeds which will maintain the desired air-flow and cabin pressure at various altitudes. Two fundamental problems are

1. Providing a variable-ratio transmission between the engine and the blower.

2. Controlling the blower speed to maintain the required air delivery.

In some cases a third problem arises because the point of air delivery is at a considerable distance from the engine, necessitating either a long transmission of power or the use of long air ducts. Requirements for remote supercharger drives of moderate power may be met by means of a variable-voltage electric coupling. By using suitable motor characteristics the air delivery of a blower connected to such an electric coupling can be controlled by a simple regulator designed to vary current in proportion to voltage. Requirements for the electric equipment are developed, and laboratory tests on a nine-horsepower model are presented to demonstrate that the equipment meets the specified performance.

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AIRCRAFT cabin-supercharger devices are required to deliver an increasing volume of air as the altitude increases. It usually is desired to maintain outside pressure up to 8,000 feet; to maintain the pressure equivalent of 8,000 feet from 8,000 to 30,000 feet; and then to let the cabin pressure decrease at higher altitudes to maintain safe pressure differentials. A certain minimum air delivery is necessary to meet the oxygen requirements of the crew, so that the usual conditions of operation will be a constant weight of air flowing from the blower each minute, cabin pressure fixed at the pressure equivalent to 8,000 feet, and inlet pressure varying according to altitude. A variable-speed centrifugal blower provides a suitable source of air delivery but requires a means of coupling it to the main engine to permit operation of the blower at the speed corresponding to altitude requirements, regardless of the speed at which the engine may be operating.

General Requirements

This paper presents an all-electric approach to the problem and is based entirely upon specifications for blower input issued by Wright Field as shown in Figure 1. An *electric coupling* is used which consists of a d-c generator driving a d-c motor. This arrangement permits any desired location of the blower. The principal purpose of this paper is to investigate the possibility of devising a suitable method of speed control to maintain automatically the desired rate of mass air delivery.

It will be noted from Figure 1 that the required power range is approximately ten to one, and the required speed range is approximately the square root of ten to one. The drive takes power from a standard high-speed engine take-off and must operate over a generator speed range of 5,000 to 10,000 rpm. By specification the electric coupling must be entirely independent of the 24-volt bus on the airplane.

A variable-voltage d-c generator driving a separately excited motor would offer a practical and flexible system of speed control, if some source of motor excitation were available. Investigation is necessary, therefore, to determine whether some simple method of speed control can be worked out using shunt, compound, or series excitation for the motor and either variable or constant voltage from the generator. A further object of the investigation is to determine whether

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plot of Figure 16 that only the complete equivalent circuit will give a fair approach to actual results. Considering the propeller damping alone leads to far too large a pulsation. On the other hand, considering only the resistance of the motor leads to far too large a damping force in the motor. The complete circuit gives a much better approach to actual conditions but it, too, deviates from the experimental curve due principally to the fact that propeller pulsations and propeller damping do not truly follow the simplified laws we have postulated for them.

Appendix

Calculation of ship-propulsion-drive constants:

$$K_s = \frac{6^4 \times 10^5}{1.036 \times 114.6} = 10.9 \times 10^5 \text{ foot-pounds per radian}$$

WR^2 of motor = 8,670 pound-feet^2

WR^2 of propeller plus 25 per cent added on account of entrained water = 14,400 pound-feet^2

Critical speed

$$= \frac{1}{2\pi}\sqrt{10.9 \times 10^5 \left(\frac{32.2}{8{,}670} + \frac{32.2}{14{,}400}\right)}$$

$$= 12.8 \text{ vibrations per second}$$

which is 256 rpm for the third harmonic pulsation of the three-bladed propeller.

$$K\phi = \frac{800}{250} \times \frac{5{,}250}{1{,}300} = 12.9 \text{ pound-feet per ampere}$$

$$K_e\phi = \frac{500 \times 60}{250 \times 2\pi} = 19.1 \text{ volts per radian per second}$$

K_p = Propeller torque constant for use in circuit of Figure 6

$$= \frac{\text{Torque}}{(w_{ps})^2} = \frac{16{,}800}{(26.2)^2} = 24.5 \text{ pound-feet per (radian per second)}^2$$

$R = 0.01109$ ohm at 75 degrees centigrade —from design details

$$\frac{K_e\phi \times K\phi}{R} = 22{,}200 \text{ pound-feet per radian per second—resistive damping constant}$$

Inductance = $L = 4.77 \times 10^{-4}$ henry

In making the calculations, the propeller-torque pulsation has been assumed at six per cent of the mean torque rather than the more commonly assumed value of ten per cent, since it is more nearly correct in this case. A verification of this is obtained by employing the equivalent circuit to calculate the armature load-current variation at the critical speed. This amounts to five per cent of rated current and checks rather closely with experimental values obtained by an oscillographic test.

The last column in Tables I, II, and III gives the vibration in per unit of full-load torque pulsation. Actually in plotting these results we assume a six per cent torque pulsation.

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2. PRACTICAL SOLUTION OF TORSIONAL-VIBRATION PROBLEMS (book), W. K. Wilson.

3. TEST OF TRANSIENT CONDITIONS IN MANEUVERING A COAST GUARD HARBOR CUTTER, H. H. Curry, J. C. Fink. Society of Naval Architects and Marine Engineers *Transactions*, volume 46, 1941, page 100.

the specified speed control may be accomplished simply by controlling the relation between speed and torque or whether a pressure-sensitive device must be used to control speed in order to obtain the specified speed for each altitude.

Motor Characteristics

Specifications of horsepower and speed versus altitude as given in Figure 1 may be converted into a speed–torque curve to facilitate investigation of motor performance requirements. The speed–torque curve is plotted in Figure 2 and proves to be a straight line which may be expressed as

$$n = 2{,}100\ T \qquad (1)$$

where n represents speed in rpm and T represents torque in pound-feet.

The internal torque which must be developed by the motor will be considerably more than the value indicated by equation 1 because of friction, windage, and rotational iron loss. An approxi-

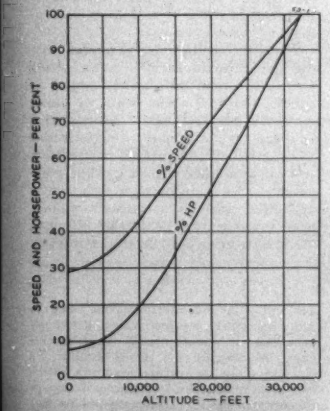

Figure 1. Specification of speed and horsepower versus altitude for the input to the blower of the supercharger

100 per cent speed = 10,000 rpm
100 per cent horsepower = 9 horsepower

mate expression for the internal torque would be

$$n = 1{,}700\ T \qquad (2)$$

In this expression the losses in torque have been assumed proportional to speed; that is, brush and bearing friction at standstill and also the nonlinear components of windage and iron loss have been neglected.

When other conditions remain constant, the torque required to drive a centrifugal blower varies with the square of the speed of the impeller. A series of speed–torque curves for the blower has been added to Figure 2 for each 5,000 feet of altitude. These curves are constructed easily by selecting the appropriate speeds from Figure 1, and setting the torque proportional to the square of the speed through the same speed–torque points on Figure 2. It will be observed that a motor having a speed–torque curve meeting the specified values will operate the blower at the correct speeds, because the intersections of the speed–torque curves are single-valued and at low speeds motor torque is always greater than the blower torque.

Perhaps this explanation needs emphasis. If the motor can be made to provide the speed–torque relation shown in Figure 2, it will operate at the speci-

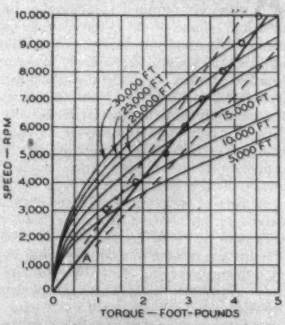

Figure 2. The specifications of Figure 1 converted to a conventional speed–torque curve

Superimposed are the speed–torque curves of the blower for each 5,000 feet of altitude and also test points obtained with the model equipment

O—Test points
A—Specified speed–torque curve with 15 per cent speed band

fication speed and only at this speed at any altitude within the range covered by the specification, *and no other altitude-sensitive control is required.*

The proposal that a motor be designed with deliberate intent to have speed increase with increasing torque is startling to a motor designer. A motor with only a slight rising characteristic may hunt violently on a load having appreciable inertia, and here it is proposed that the speed increase directly with torque. The curves of Figure 2 are reassuring, however; no instability will result from any straight-line speed–torque curve passing through the origin. It remains then to devise some way to produce the unconventional speed–torque curve required.

A d-c motor responds only to voltage, current, and flux, and the desired motor performance must be expressed in terms of these quantities. The fundamental equations for speed and torque are

$$e = n\,k\,\phi \qquad (3)$$

where e equals counterelectromotive force, n equals rpm, ϕ equals flux per pole in kilolines, and

$$k = \text{conductors} \cdot \frac{\text{poles}}{\text{circuits}} \cdot 10^{-8} \cdot \frac{1}{60} \qquad (4)$$

$$T = 7.03\,k\,\phi\,I_a \qquad (5)$$

where I_a equals armature amperes, and T equal torque in pound-feet.

By substitution

$$e = 1.192\ k^2\,\phi^2 I_a \cdot 10^4 \qquad (6)$$

Equation 6 gives the relations between induced voltage, flux, and armature current for any motor operating on the assumed speed–torque curve in equation 2. A preliminary study of these relations may be made by assuming voltage, flux, and current to be held constant in turn as shown in Table I.

Table I. Range of e, ϕ, and I_a From Minimum to Maximum Altitude

e	ϕ	I_a
Constant	$\sqrt{10}$ to 1	10 to 1
1 to $\sqrt{10}$	Constant	1 to $\sqrt{10}$
1 to 10	1 to $\sqrt{10}$	Constant

Analysis of Table I indicates that the generator will be of the same size for all three arrangements; that is, the maximum output is ten times the minimum output, if the increase is all in current equally, divided between current and voltage, or all in voltage. This is a natural consequence of the fact that the load on the generator is completely independent of generator speed. However, this condition does not obtain for the motor. If cooling considerations are neglected, the motor would be about three times as large for constant voltage as it would for either constant flux or constant current. A constant-voltage motor would have to deliver maximum power with less than 30 per cent of its maximum flux capacity being utilized. Also, a constant-voltage system would require two regulators: the first to maintain constant voltage, and the second to keep the flux in the motor in inverse proportion to the armature current. Needless to say, the flux regulator would be a difficult instrument to devise.

Constant-flux operation with voltage directly proportional to current results in a motor of reasonable weight but involves some difficult control problems. Again, two regulators would be required: one to hold field current constant regardless of voltage, and the second to vary voltage in proportion to current. The field wind-

ing would be likely to overheat at low speeds, since field losses would remain at full value while ventilation would fall off rapidly.

Constant-current operation with voltage varying over a ten-to-one range appears somewhat more practical, although it also presents a difficult ventilation problem at low speed, since the copper losses remain as high at minimum speed as they are at maximum output. Examination of equation 6 indicates that for constant-current operation the flux must vary as the square root of the voltage. This condition may be approached over a limited range by careful design of the magnetic circuit, by using shunt excitation, and by using pole-face windings to prevent field distortion under load. The regulation problem would be simple, as a standard voltage regulator could be used by replacing the potential coil with a current coil.

From these considerations it appears that the ideal condition is a compromise approaching the constant-current condition but with some change in current with load to reduce the range of voltage required and to reduce copper losses at low speeds. Further examination of equation 6 will show that, if the relation between current and voltage is of the form:

$$I = I_a + Ae \tag{7}$$

the relation of flux and voltage will be

$$\phi^3 = \frac{e}{1.192\, k^2 (I_a + Ae)} \tag{8}$$

This is a promising equation, since, if Ae is small compared to I_a, the flux will be proportional to the square root of the voltage (as before) for small values of voltage but will approach a saturation value as e approaches infinity. A voltage regulator to meet the requirements of equation 6 is very simple; it requires a current coil to balance the spring forces at current I_a and a differential potential coil to bias the regulator, so that each increment in voltage requires a proportional increment in current for equilibrium.

Before one proceeds to the actual design of a motor, equation 6 must be modified to include brush drop, armature-circuit resistance drop, and shunt-field amperes. The armature current becomes

$$I_a = \frac{V - (1.0 + R_a I_a)}{1.192\, k^2 \phi^2 \cdot 10^4} \tag{9}$$

where V is terminal voltage, R_a is the resistance of the entire armature circuit, and the brush potential drop is assumed constant at one volt.

The total line current is

$$I_L = I_a + \frac{V}{R_f} \tag{10}$$

where I_L equals line current and R_f is the hot resistance of the shunt field.

At this point it is necessary to make a tentative motor design and then to determine whether operation within the specified limits will be possible by means of a regulator working to equation 7. For the model designed to meet the specifications of Figure 1, a four-pole motor with provisions for generous pole-face windings was selected. Accurate compensation of armature ampere turns is used to prevent field distortion. The armature has 82 conductors and two circuits, so that k is $2.74 \cdot 10^{-4}$. The total resistance of the armature circuit is 0.013 ohm. Curvature was introduced into the saturation characteristic of the motor at low excitations by notching the backs of the poles to provide thin sections of restricted area. These thin sections saturate at low values of flux and then behave like an increasing air-gap length at higher values of flux. The actual saturation curve is plotted in Figure 3, and it will be noted that the curve does not deviate greatly from a square curve. The hot-field resistance is ten ohms.

Various values of V may be assumed, and corresponding values of ϕ taken from curve 1 of Figure 3. Equations 9 and 10 are then used to find the relation between V and I_L. This relation has been plotted as curve 3 of Figure 3. It will be noted that this curve is not linear; the actual shape varies with the shape of the saturation curve and may be modified considerably by slight changes in this curve. Over the principal operating range, however, the relation of I_L and V is reasonably close to the linear curve:

$$I_L = 140 + 0.75\, V \tag{11}$$

shown as curve 2 on Figure 3.

It is obvious that very careful precautions must be taken in the design and construction of the motor to minimize the effects of residual voltage, as otherwise, the performance of the system will differ widely between ascending and descending tests.

A nine-horsepower motor was built to these specifications and tested with a regulator which controlled current and speed per the test points shown in Figure 3. Speed-versus-voltage readings are shown in Figure 3, and speed-versus-torque readings are shown in Figure 2. The test points are well within specification limits except for the relatively unimportant points at the extreme low end of the speed range.

Generator Characteristics

No special characteristics are necessary for the generator insofar as meeting the requirements of the regulating system. Any generator capable of delivering the required range of voltage and the required range of current will be satisfactory so long as it meets general specifications for aircraft generators. For the model built and tested for this investigation the stacking was lengthened on a 5,000-rpm 30-volt generator, so as to provide a maximum output of 50 volts at 185 amperes. The generator is compensated fully to provide good commutation over a wide range of output at any speed from 5,000 to 10,000 rpm. A four-pole design with 51 commutator bars provides a very conservative value of volts per bar for high-altitude operation. Aside from voltage rating, the generator is of conventional design.[1,3]

Regulator

A schematic diagram of the regulator is shown in Figure 4 and a photograph of the regulator in Figure 6. The basic

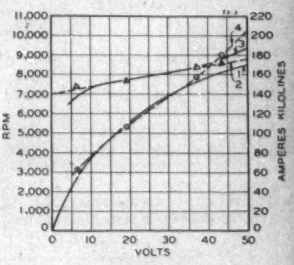

Figure 3

1—Motor saturation curve, flux versus volts

2—Test volt-ampere curve for regulator, $I_L = 140 + 0.75V$

3—Calculated volt-ampere curve for regulator,

$$I_L = \frac{V - (1 + 0.013 I_a)}{8.95 \phi^2 \cdot 10^{-8}} + \frac{V}{10}$$

4—Test speed-voltage curve, revolutions per minute versus test voltage

principle of the regulator is very simple. The operating coils consist of

1. A heavy coil of a few turns carrying the entire line current.

2. A differential-potential coil carrying current in proportion to system voltage.

This regulator will adjust the generator field until sufficient current flows, so that the algebraic sum of the ampere turns in the current coil and the opposing ampere turns in the potential coil will produce enough flux to balance the regulator spring. Each time the regulator acts to increase the current, it does so by raising the system voltage. With increasing voltage it takes higher and higher values of current to produce equilibrium.

A decrease in torque, such as is produced by an increase in altitude, tends to reduce the current drawn by the motor in proportion to the reduction in torque required to operate the blower. The

regulator, however, cannot permit a decrease in current; instead it operates to raise the excitation on the generator. The increased system voltage increases

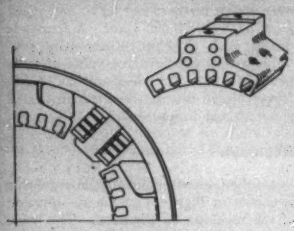

Figure 4. A quarter section of the magnetic circuit of the motor

Inset shows the restricted pole section which produces the desired saturation characteristics

speed of the blower, and the increased speed increases the torque. This action continues, until both current and voltage have increased to a new equilibrium point for the regulator; at the new operating point, horsepower, torque, and speed will have all increased to maintain the original air delivery in pounds per minute.

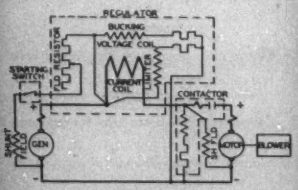

Figure 5. Schematic diagram of the electric coupling system

Two refinements are necessary to make the regulator entirely satisfactory. In the first place, a shunt-wound generator never would build up voltage with a low-resistance motor across its terminals. For this reason, a starting contactor is provided which will open the motor circuit until the generator has built up to a low voltage. During starting the current regulator necessarily acts as a current limiter, preventing currents in excess of the regulator setting by inserting the control resistance in the generator-field circuit. The drop in voltage will cause the starting contactor to open, and the system will cycle several times as the blower motor comes up to speed. This is not harmful in any way, as the line current is practically zero at the instant the contactor opens, and the only effect is to increase the time required for acceleration to full speed. A series coil is provided to hold the contactor in at low voltages.

The second device which must be added to the basic regulator is a voltage-limiting device which acts to prevent the voltage from exceeding about 55 volts. This device is necessary because the system tends to be self-destructive in the event of loss of load for any reason. The device acts on the armature of the regulator as soon as the calibration voltage is reached and destroys regulator equilibrium in such a way as to make it regulate for 55 volts. Since the motor is shunt wound, motor speed is limited to a value only slightly over the maximum rated speed of 10,000 rpm.

Figure 6. The generator (left) and motor (right) of the electric coupling

Figure 7. The regulator which controls the relation of current to voltage

The voltage-limiting device may be seen to the back and right of the main regulator

Conclusions

It has been demonstrated that it is possible to design a motor with characteristics such as will result in a speed–torque curve with torque directly proportional to speed over an appreciable range of output, when the motor is operated from a system having voltage and current control of the form $I=I_o+AV$. It also has been shown that a motor with such a speed–torque curve will meet the requirements of specifications intended to assure a constant rate of mass air delivery at any altitude between 8,000 and 30,000 feet when used with a centrifugal blower operating to supercharge an airplane cabin. A simple regulator to control current and voltage has been described.

A model has been built and tested, and found to meet the specified speed–torque requirements within narrow limits. It was found during the tests that the steepness of the speed–torque curve could be adjusted readily by changing the ratio of current-coil ampere turns to potential-coil ampere turns and that the entire power-output level could be raised or lowered by adjusting the spring tension on the regulator. No tests were made of actual altitude performance.

The chief difficulties with the system appear to lie in the accuracy required of the motor characteristics, particularly in regard to control of the magnetic circuit. Elimination of residual effects requires careful selection of magnetic materials and elaborate annealing; the accuracy usually built into a regulator must, to a lesser degree, be built into the motor, since the motor characteristics form an important part of the regulating system. Some minor difficulties also may arise from temperature effects, but these do not appear important so long as the permissible speed variation is 15 per cent.

The speed-limiting action which takes place at maximum altitude appears in line with recent proposals to allow cabin pressure to decrease at altitudes above 30,000 feet to lessen danger to personnel in the event of rupture of the airplane cabin.

The project was a very interesting experiment; its future possibilities must be exploited by the experimental section of the Army Air Forces at Wright Field.

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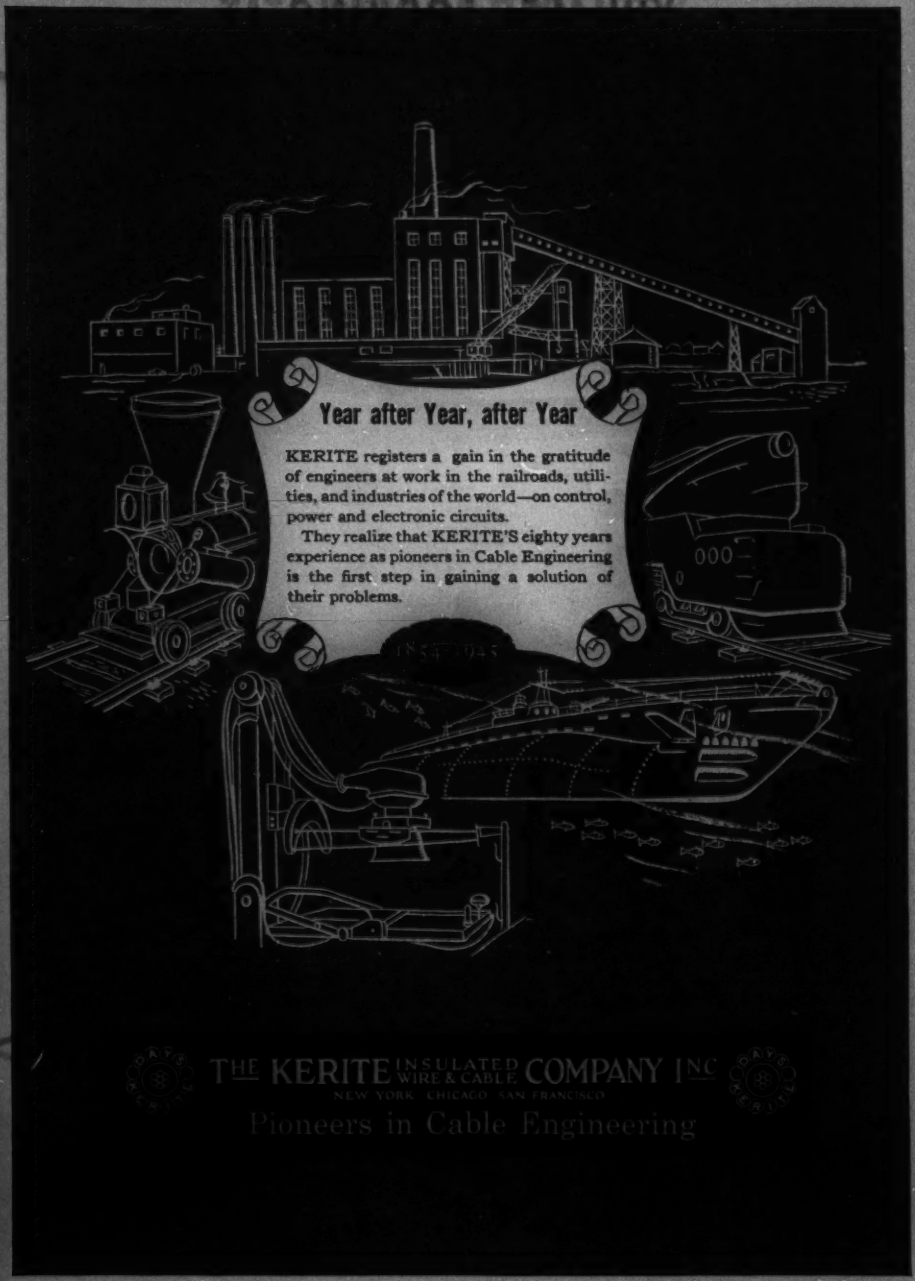
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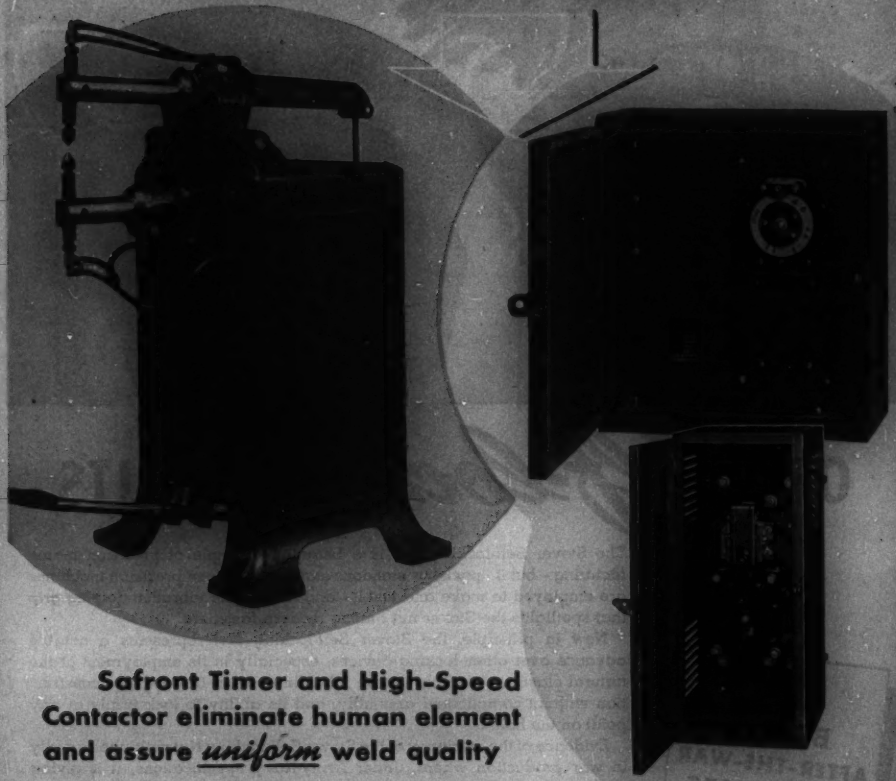

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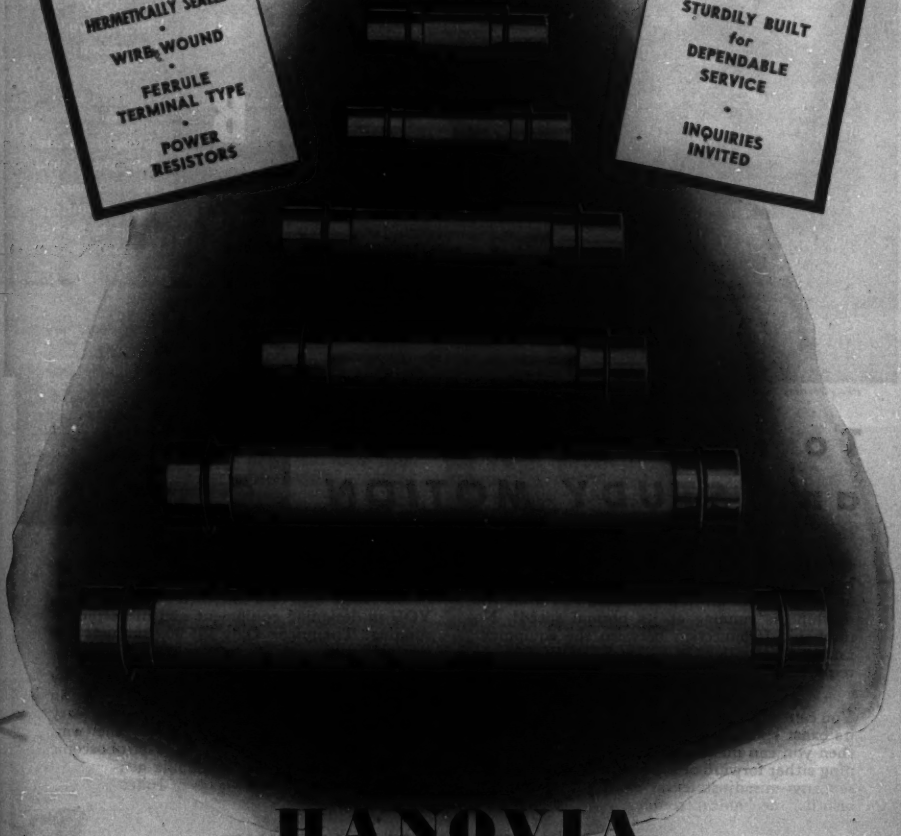

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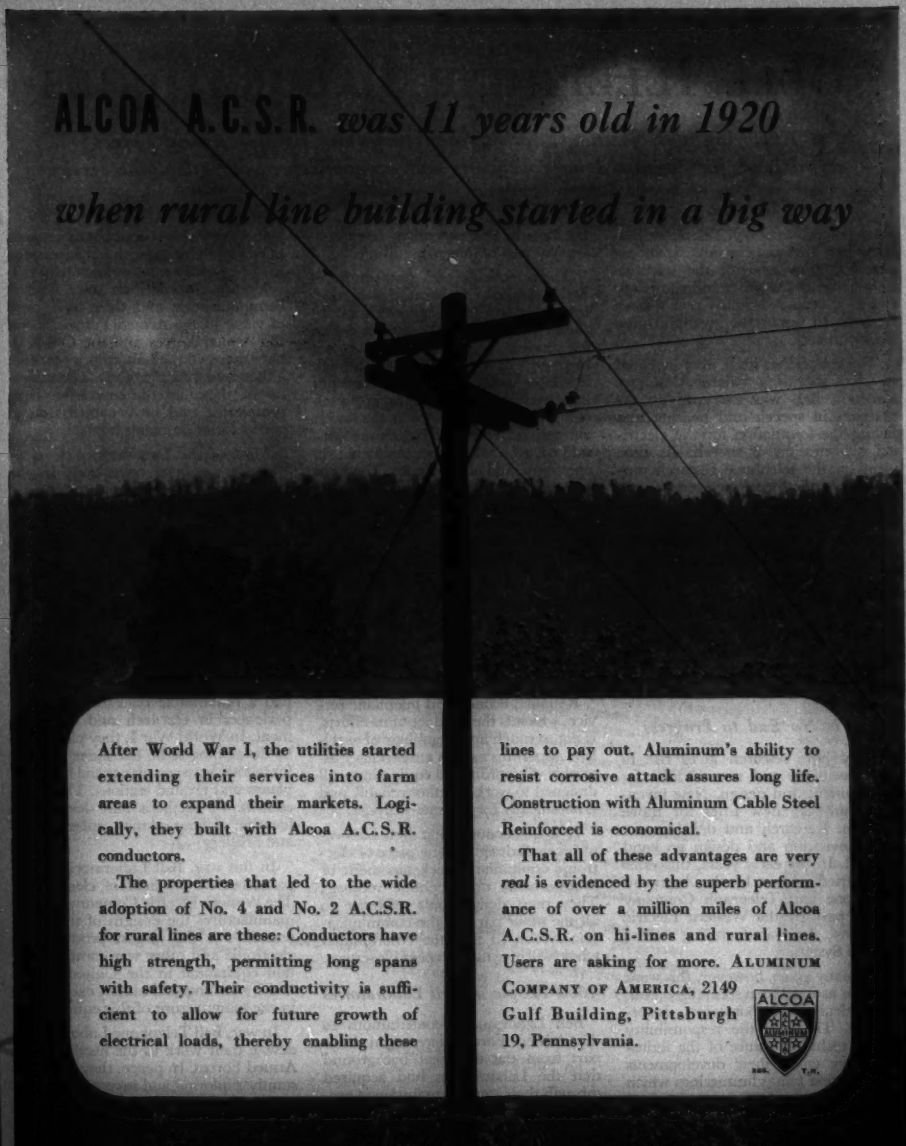

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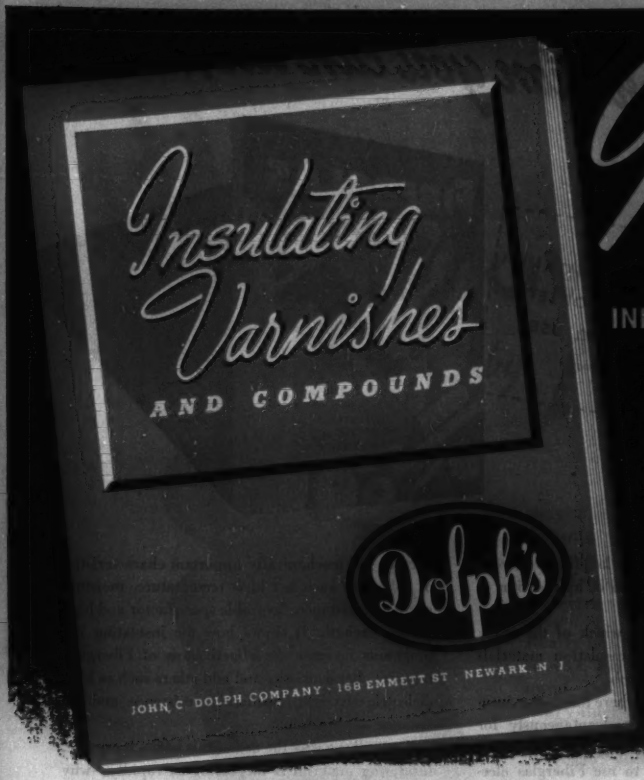

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Insulating Varnish Specialists

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Here's information you can use, NOW!

New FIBERGLAS* ELECTRICAL INSULATION MATERIAL BOOKLET . . . TELLS WHAT TYPE TO USE, WHERE AND HOW . . .

This free, new booklet will be helpful to anyone concerned with the specification or application of electrical insulation.

It will help you determine which of the many types of Fiberglas electrical insulation materials should be used for a specific job.

The booklet will show you where this better insulation material can be used advantageously for electronic, radio and electrical applications.

It will indicate the ways to use Fiberglas electrical insulation material to obtain all of the benefits which it affords.

Containing complete information about Fiberglas, the new booklet illustrates Fiberglas fibers and filaments twisted into yarns, served on wires, woven into tapes and cloths, braided into sleevings and formed into tying cords.

It describes the unique combination of electrically and mechanically important characteristics of Fiberglas such as: high temperature, moisture and acid resistance, favorable space factor and high tensile strength. It shows how the insulating impregnants increase the effectiveness of Fiberglas' inherent characteristics and add others such as high dielectric strength, insulation resistance and resistance to abrasion.

You will see why the use of this basic, inorganic, insulating material is increasing so rapidly—why so many designers, manufacturers and repair shop operators prefer it.

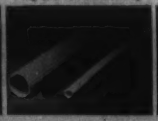
Be sure to have a copy of this new booklet in your file for ready reference. Write for your copy today—there is no obligation. Address: *Owens-Corning Fiberglas Corporation, 1859 Nicholas Building, Toledo 1, Ohio. In Canada, Fiberglas Canada Ltd., Oshawa, Ontario.*

Fiberglas varnished cloth and tape

Fiberglas insulated wire

Fiberglas tying cord

Fiberglas saturated sleeving and varnished tubing



Fiberglas laminated plastics

Fiberglas-mica combinations

FIBERGLAS

*T. M. Reg. U. S. Pat. Off.

ELECTRICAL INSULATION MATERIAL

a NEW *Industrial* POWER TUBE *by* Federal

Federal presents a new and rugged power tube that fills an immediate demand — a power tube that has been *specially* designed for industrial use in high-frequency heating equipment, both dielectric and induction.

Really built to withstand the constant jars, shocks, and vibration commonly encountered in manufacturing operations, this heavy-duty vacuum tube is very conservatively rated, and will stand up under extremely hard usage.

Widely spaced, unusually sturdy filament and grid elements, without internal ceramic insulation, give this tube a ruggedness that makes it the logical choice for dependability in the design of industrial heating equipment.

For industrial power tubes, and also for rectifier and transmitting tubes, see Federal first... because "Federal always *has* made better tubes."

TECHNICAL DATA FOR TYPE F-5303

Filament Voltage	11.0 volts
Filament Current	27.5 amps.
Maximum Ratings for Maximum Frequency of 50 Mcs.	
DC Plate Voltage	3500. volts
DC Plate Current	1.0 amp.
Plate Dissipation	1200 watts
Overall Height	app. 7"
Maximum Diameter	3½"
Supplied with 6 "flexible copper leads, 2 on each terminal.	
Type of Cooling	Forced-air
(Also supplied for water-cooling, type F-5302.)	

FEDERAL TELEPHONE & RADIO — FTR

Federal Telephone and Radio Corporation

A Unit of the IT&T Associate

Newark 1, New Jersey

COLLINS ENGINEERING AND EIMAC TUBES
achieve outstanding results

COLLINS Type 231D-11 (Navy TDH)
Multi-frequency transmitter

Output CW—5 KW; Output 'Phone—3 KW 100% modulated with a pair of Eimac 450TL tubes in class "B" audio; continuous coverage from 2 MC to 18.1 MC with 11 preset channels in that range and complete manual coverage throughout whole range. Capable of completely unattended remote control operation and of A1, A2 and A3 type emission. Audio characteristics: plus or minus three DB from 150 to 3,500 cycles. Total harmonic distortion less than 10%. The transmitter can be terminated into a 50 to 1,200 pure resistive load at zero degrees phase angle. 70 to 850 ohm load at plus or minus 45 degrees and 100 to 600 ohms at plus or minus 60 degrees.

This Collins type 231D-11 (Navy TDH) radio transmitter is an outstanding demonstration of the value of capable engineering coupled with the intelligent choice and use of vacuum tubes.

It is the latest of a series of Collins Autotune, quick shift transmitters which were originally introduced in 1939, and which use Eimac tubes in the important sockets. In the 231D-11, two Eimac 750TL tubes in parallel make up the power amplifier, while a pair of Eimac 450TL tubes in class "B" are used as modulators for voice and MCW emission.

Mr. F. M. Davis, General Manager of the Collins Engineering Division, says: "Eimac tubes have been found to be reliable, rugged and capable of withstanding the severe overloads encountered during equipment tests, without damage." Statements like this, coming from such men as Mr. Davis, offer proof that Eimac tubes are first choice of leading engineers throughout the world.

Write for your copy of Electronic Telisis — a 64 page booklet fully illustrated — covering fundamentals of Electronics and many of its important applications. Written in layman's language.

Follow the leaders to
Eimac
reg. U. S. pat. off.
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Eimac has received
8 ARMY-NAVY "E" AWARDS
for production efficiency
San Bruno 5, Salt Lake City 3

EITEL-McCULLOUGH, Inc., 956 San Mateo Ave., San Bruno, Calif.
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Hours to Plot it—a Second to See it on a CATHODE-RAY TUBE

Curve tracing by means of cathode-ray tubes is faster, more accurate, more economical, and permits simultaneous comparison of several curves

Electrical measurement with RCA cathode-ray oscillograph tubes has saved countless hours for radio-set manufacturers. They use this method to trace the resonance curves of the r-f stages of receivers—and for many other purposes, too.

This use of RCA cathode-ray tubes has already been extended to fields other than radio—to applications such as determining pressure curves for internal-combustion engines, studying rapid variations in strain, measuring extremely short time-intervals, and for plotting other data which can be expressed graphically.

And these are but a few of hundreds of uses for cathode-ray tubes. Any physical or chemical phenomenon which can be translated into electrical impulses—and there are few which cannot—can be studied visually on the screen of an RCA cathode-ray tube, whether depicting a single, static condition, or a number of simultaneous, fluctuating conditions.

Perhaps you are building equipment in which cathode-ray tubes could be used to advantage for visual indication of proper adjustment, or measurement of performance, or the correlation of several variables of operation.

If so, why not take advantage of the expert knowledge of RCA tube-application engineers? RCA has the tubes, the engineering "know-how," and the willingness to help you utilize cathode-ray tubes in your products.

Address inquiries to RCA, Commercial Engineering Section, Dept. 62-38A, Harrison, New Jersey.

The Magic Brain of all electronic equipment is a Tube...and the fountain-head of modern Tube development is RCA.

RCA

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION • CAMDEN, NEW JERSEY

V... — Buy More War Bonds V... —

THE STORY

OF THE WELD IN COPPERWELD

Lathe turned from a section of a Copperweld billet, this chip clearly illustrates copper and high-strength alloy steel permanently united. The two metals are welded to each other and cannot be separated except by the destruction of the material itself. This permanent weld is achieved by the Copperweld process of molten welding.

By specifying Copperweld you are assured of the electrical and mechanical characteristics most vitally needed for dependable and economical service—the high conductivity and corrosion resistance of copper plus the rugged strength of steel.

Write for our Engineering Data Book.

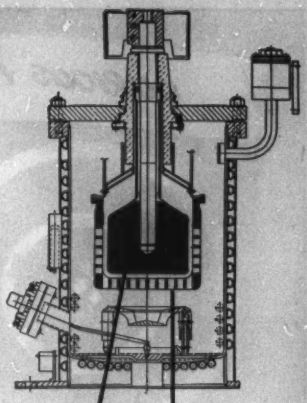
Copperweld

RODS, WIRE AND STRAND

COPPERWELD STEEL COMPANY

GLASSPORT PENNA.

"Unless you can express it as a *Number* you have no information"



THAT'S AN UNWRITTEN LAW in many laboratories today. Because "National" graphite's purity—99.979%—could be expressed as a number, the manufacturer's engineers knew what its performance characteristics would be when used as the anode and anode shield material in this Ignitron Rectifier.

Across the nation, banks of these rectifiers are serving war plants, traction companies, shipyards and mills efficiently and dependably.

Engineers have long known that graphite does not fuse, soften or warp, and has nearly perfect heat radiation properties. Thus, in many types of both vacuum and gas-filled industrial and radio tubes where great heat must be dissipated, or where warpage of multiple tube components must be prevented, graphite is the ideal material.

As pioneers in the carbon and graphite manufacturing business in America, National Carbon Company has brought to highest perfection the art of making high-purity graphite. That is why "National" High-Purity Graphite is most frequently specified for vital industrial and radio tube components. Graphite of even higher purity is supplied for some applications. We welcome the opportunity to discuss the advantages of this "National" electronic graphite.

NATIONAL CARBON COMPANY, INC.

Unit of Union Carbide and Carbon Corporation

UCC

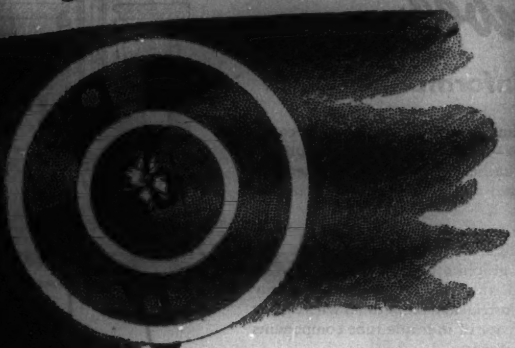
General Offices: 30 East 42nd Street, New York 17, N. Y.

Division Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

The registered trade-mark "National" distinguishes products of National Carbon Company, Inc.

Keep your eye on the infantry . . . the Doughboy does it!

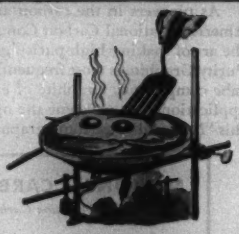
CURIOUS FACTS ABOUT LIGHTING



LIKE SHOOTING FISH IN A BARREL . . . There was a time when Jap Zeros could "sit in the sun" and come in with guns blazing—protected from our gunners by blinding sunlight. Not long ago, they had an unpleasant surprise. U. S. Army and Navy gunners now have a *new Westinghouse gunsight lamp* that lets them fire with deadly accuracy—directly into the sun. Formerly, our gunners could aim within only 15 degrees of the sun, leaving a dreaded "blind spot". This has now been removed—and, with it, a lot of Japs.

Lamps of 10,000 different types, using from 1/10th to 10,000 watts—incandescent, fluorescent, infrared, ultraviolet lamps, produced at the rate of about 1,000,000 units daily—lamps for seeing, for heating, for fighting disease—wherever you see the Westinghouse Mazda Trade Mark, you'll find top quality!

CEILING, 2000 . . . Vital "ceiling" information is provided for American fliers by alidade sighting device, which "draws a bead" on a cloud—illuminated by giant Westinghouse searchlight. Height is read directly in hundreds of feet.



HAM AN' . . . New sealed-beam landing lights for army bombers are so powerful that a Westinghouse engineer actually cooked a meal on the surface of an upturned lens. Infrared rays did the trick.

DAVY JONES could find good use for this 5000-watt sea salvage lamp. Inside are loose grains of tungsten which the diver can whirl against the glass—to scour off cloudy deposits emitted by the filament.

SELF-CONTAINED SUN LAMP, developed by Westinghouse, produces comfortable warmth with infrared, as well as beneficial ultraviolet rays. Mercury vapor, electrodes, reflector, and incandescent filament are sealed in a reflector bulb of special glass, which screws into any lamp socket.

MAXIMUM "SEE-ABILITY" is provided by Westinghouse 3-kilowatt mercury lamps—in blimp hangars, airplane factories, steel mills, etc. These lamps produce 120,000 lumens of light.

Tune in:
JOHN CHARLES THOMAS
Sunday, 2:30 pm, EWT, NBC

Westinghouse
PLANTS IN 25 CITIES OFFICES EVERYWHERE

Tune in: TED MALONE
Mon. Wed. Fri. 10:15 pm, EWT,
Blue Network

The train of events leading to Victory is speeding right into Tokyo and Berlin . . . and many of the deciding factors may be traced back to the service of skilled hands on the home front.

Here at Cornell-Dubilier skills handed down from mother to daughter as well as from father to son have helped to bring Victory nearer. Some of our workers have been with C-D almost as long as modern capacitors have been in existence. Others are proud — as we are — of their five, ten and twenty years with C-D.

C-D's expanded production facilities and expert workmanship are at your service. Write us for further information. Cornell-Dubilier Electric Corp., South Plainfield, N. J.

TYPE 6 Medium Power Mica Transmitter Capacitor. *Designed for a wide variety of r.f. applications where size and weight must be kept to a minimum. Patented series mica construction; vacuum impregnated — resulting in low loss, high insulation — no air voids; special low-loss filler reduces stray losses.*

CORNELL-DUBILIER CAPACITORS 1910 1944

MICA • DYKANOL • PAPER • WET AND DRY ELECTROLYTICS

ALSO AT NEW BEDFORD, BROOKLINE, WORCESTER, MASS.; PROVIDENCE, R. I.

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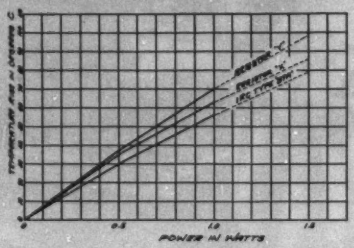
IRC is ready with...

THE NEW BTA RESISTOR



Lowest Temperature Rise

Like all BT Resistors, the operating temperature of the new BTA is *lower* than other resistors of comparative size!

Only the extreme pressure of essential war production has delayed our release of this small one-watt AWS RC 30 type *insulated* resistor. You'll find the BTA insulated resistor a worthy and important addition to the BT family. Built to meet American War Standards specifications, the BTA is only 0.718 inches long and 0.250 inches in diameter. Wattage rating, 1 Watt at 40° C ambient. Voltage rating, 500 volts. Minimum range, 330 ohms. Maximum range, Standard: 20 megohms.

Write today for comprehensive bulletin containing engineering data and charts.

DESIGNED FOR PERFORMANCE · PRODUCED TO SPECIFICATIONS

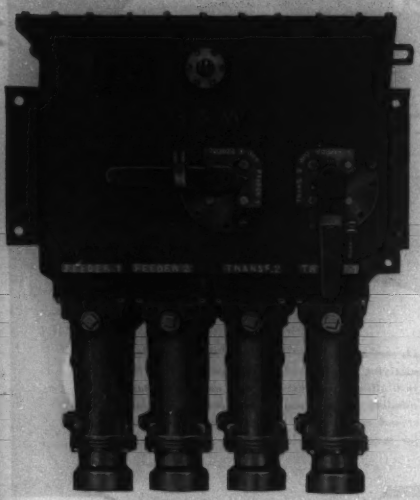
IRC

INTERNATIONAL RESISTANCE CO.

401 NORTH BROAD STREET PHILADELPHIA 8, PA.

COMING... COMING... COMING... COMING

"A remarkable development in compactness and simplicity"

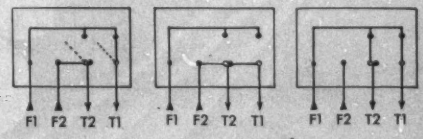


G & W TYPE "RAK" SUBWAY OIL SWITCHES

provide for

Connecting 2 loads independently to 2 feeds or connecting both loads to either feed circuit.

With only 2 sets of Links



Fully metal enclosed water-tight construction with unit sealed cable heads. Links are operated by external levers.

Standard ratings:
3 pole, 7500 volts, 400 amperes.
3 pole, 15000 volts, 400 amperes.

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New Bul. No. 743 has 36 pages with prices and detailed dimensions of various forms of G & W TYPE "RA" oil switches and transformer disconnects.

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IN CANADA—POWERLITE DEVICES, LTD., TORONTO

Good Start for a Power Transformer

Operator at Allis-Chalmers' Pittsburgh plant applying Natvar varnished cambric to form the insulating barrier between core and low voltage winding of a Power Transformer. Multiple strand conductor is used for compactness and for maximum reduction of eddy current losses.

ALLIS-CHALMERS Power Transformers are designed and built for continuity of operation with minimum of maintenance.

In spite of increased industrial loads demanded by the war effort, these transformers have operated far beyond their rated capacity for extended periods without interruption, without other than routine maintenance. *That's performance!*

It is a source of considerable satisfaction to us that Natvar insulating materials, because of their high uniformity, were selected for this important application.

What are your requirements? Write, wire or phone us for deliveries — either from the stock of a wholesaler near you — or direct from our own.

Natvar

- Varnished cambric—straight cut and bias
- Varnished cable tape
- Varnished canvas
- Varnished duck
- Varnished cellulose acetate
- Varnished Fiberglas cloth
- Varnished papers
- Varnished tubings and sleevings
- Varnished identification markers
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TELEPHONE RAHWAY 7-2171 — CABLE ADDRESS NATVAR: RAHWAY, N. J.

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PERMANENT MAGNETS MAY DO IT BETTER

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To determine the type of magnet for any industrial need calls for exceptional experience and research training in magnetics. As exclusive manufacturers of permanent magnets for over thirty-four years, this company has pioneered many advances in magnetic technology. Our technical and engineering staff can help you to solve your problems in magnetization. Write for consultation . . . and ask for a copy of our informative article, "*Permanent Magnets Have Four Major Jobs*," from which the above illustration is taken.

★ THE INDIANA STEEL PRODUCTS COMPANY ★

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Specialists in Permanent Magnets Since 1910

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RAYTHEON VOLTAGE STABILIZERS

CONTROL VARYING LINE VOLTAGES

TO 115 VOLTS ± ½%

Ordinary A.C. line voltages as taken from supply mains often vary as much as from 95 to 130 volts. This impairs the precision operation of electrical equipment.

A Raytheon Voltage Stabilizer, built into new products or incorporated into equipment already in use, overcomes the disadvantage of fluctuating voltages by providing an accurately controlled source of power to ± ½%.

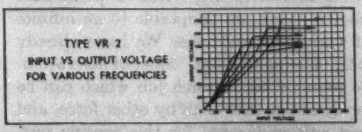
Here's what a Raytheon Stabilizer does—stabilizes varying input voltage from 95 to 130 volts to 115 volts ± ½% within 2 cycles.

Raytheon Voltage Stabilizers are entirely automatic. They require no adjustments or repeated maintenance. No moving parts assure long life. Write for bulletin DL 48-537.

EFFECT OF VARIABLE FREQUENCY

Since partial resonance is a requisite design feature, these devices are sensitive to frequency changes. The output voltage will vary in the same direction and 1.4 times the percentage change in frequency, over a range of 5% of the normal frequency.

Stabilization, however, will be within ± ½% at the output voltage which is established by the frequency.



Tune in the Raytheon radio program: "MEET YOUR NAVY," every Saturday night on the Blue Network. Consult your local newspaper for time and station

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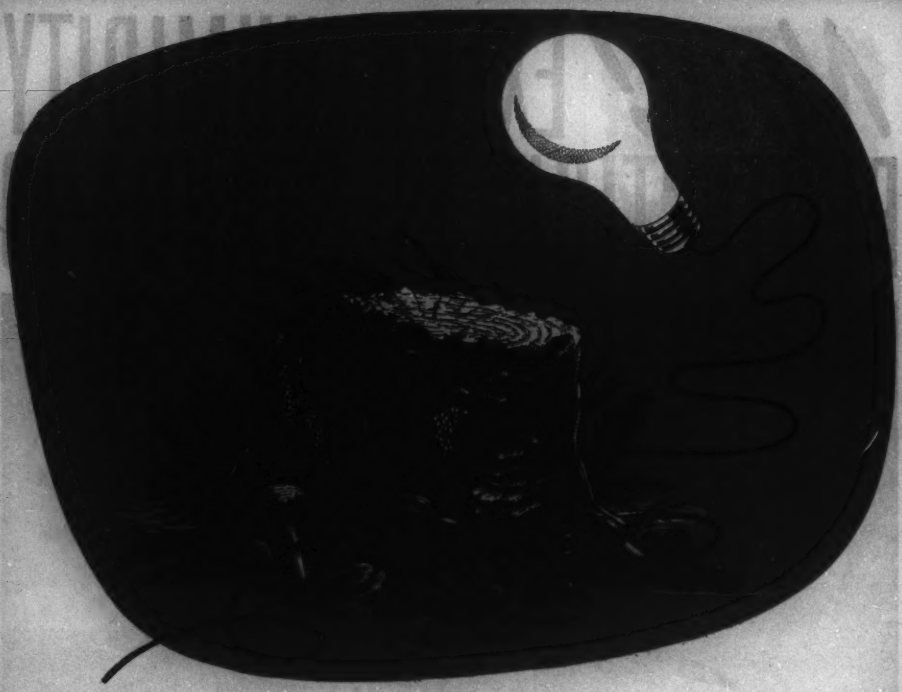
MANUFACTURING COMPANY
190 WILLOW STREET, WALTHAM, MASS.

The coveted Army-Navy "E," for Excellence in the manufacture of war equipment and tubes, flies over all four Raytheon Plants where over 16,000 men and women are producing for VICTORY.

Devoted to research and manufacture of complete electronic equipment; receiving, transmitting and hearing aid tubes; transformers; and voltage stabilizers.



Laytex surprised even its creators!

It isn't often that one wire gets a world-wide action test in a world-wide laboratory. But Laytex — the original light-weight, small diameter wire — has had just that, and has come through with flying colors.

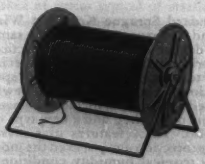
Laytex-insulated wire has followed our armed forces through arctic cold, tropic heat and moisture. It has defied insects and mold. It has been battle-tested under the most extreme conditions — and has stood up so well that it surprised even *us!*

Laytex has a record of delivering *more* electricity, *more* dependably, in *more* different jobs than any other wire we know.

Right now the entire output of Laytex Wires and Cables is going to the Armed Forces. But the day is steadily drawing nearer when manufacture will be resumed for Buildings, Police and Fire Alarms, Communications, Signalling, Power, Control, and other exacting services.

SERVING THROUGH SCIENCE TO PIONEER A NEW ELECTRICAL ERA

RUBBER INSULATION AT ITS BEST



U.S. Laytex

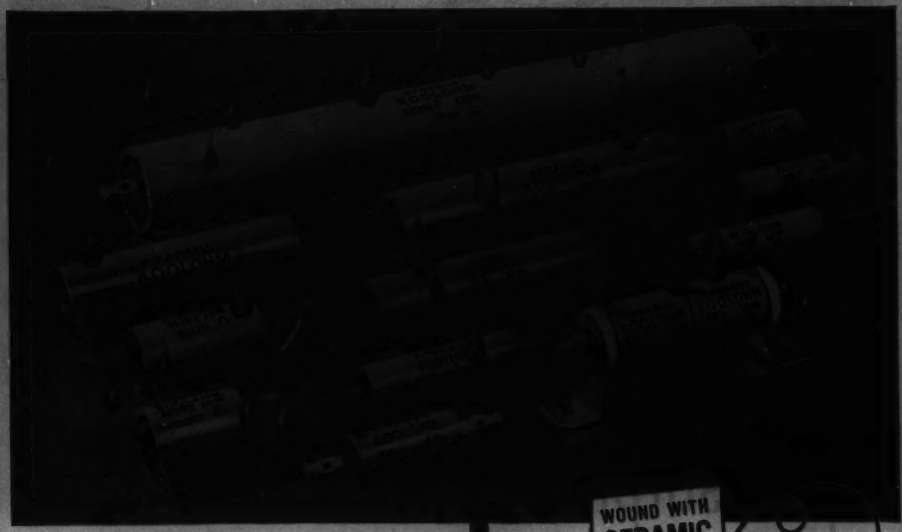
Reg. U. S. Trade Mark

WIRES AND CABLES

UNITED STATES RUBBER COMPANY

1230 Sixth Avenue • Rockefeller Center • New York 20, N. Y. • In Canada: Dominion Rubber Co., Ltd.

Now! EXTRA HUMIDITY PROTECTION IS STANDARD



. . . designed for tropical conditions . . . unbeatable on ANY job

Standard Sprague Koolohm Wire Wound Resistors now offer the same high degree of humidity protection formerly obtainable only on special order to match exacting military specifications. This construction, newly adopted as standard, includes a glazed ceramic outer shell and a new type of end seal. These features give maximum protection against even the most severe tropical humidity conditions. Type numbers remain the same except for the fact that the letter "T" has been added to designate the new standard construction.

Thus, again, Sprague leads the way in practical, truly modern wire wound resistor construction. Your job of resistor selection is greatly simplified. No need to study and choose between types or coatings. One type of Koolohms, the *standard* type, does the job —under any climatic condition, anywhere in the world!

SPRAGUE ELECTRIC COMPANY, North Adams, Mass.
(formerly Sprague Specialties Co.)

SPRAGUE KOOLOHM RESISTORS

TRADEMARK REGISTERED U.S. PAT. OFF.

The Greatest Wire-Wound Resistor Development in 20 Years

Protect Busy Motors with Deltabeston Magnet Wires

You can stop frequent failures by protecting busy motors with Deltabeston Magnet Wires. The next time your motor is sent to the repair shop for rewiring, install Deltabeston Asbestos-insulated Wires and Cables. Motors wired with Deltabeston stay on the job longer and perform with the utmost dependability even in severe operating conditions. If you use ready-made coils with class B insulation, specify Deltabeston-wound coils.

Deltabeston Magnet Wires are designed for winding motors, lifting magnets, brake coils, generators, starters and other electrical equipment. Deltabeston is insulated with asbestos purified by an exclusive process. The felted asbestos is impregnated with a resin compound to make it highly resistant to heat, moisture and most corrosive vapors. Deltabeston's soft copper conductors can be formed into the most intricate coil without rupturing the insulation. It's available in round, square and rectangular shapes.

For additional information write for our new Deltabeston Wire and Cable Catalog. It's free. Send your request to Section Y-152-32, Appliance and Merchandise Dept., General Electric Co., Bridgeport, Conn. Deltabeston Wires and Cables are distributed nationally by Graybar Electric Co., General Electric Supply Corp., and other G-E Merchandise Distributors.

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GENERAL ELECTRIC

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"SPECIAL SUPPLEMENT"

HARD-TO-FIND RADIO AND ELECTRONIC COMPONENTS

16 pages crowded with listings and descriptions of such wartime essentials as...

- METERS
- VOLUME CONTROLS
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- SPEAKERS
- RHEOSTATS
- RELAYS... and hundreds of others!

Each page overflows with critical parts and equipment . . . urgently needed by industry, laboratories, government agencies, training schools, radio servicemen, military services, etc. Everything is the product of a leading American manufacturer. All are first quality. And all are marked at prices typical of startling Concord values! Hurry! Our edition of these supplements is moving fast. And, since all items are subject to prior sale, we suggest that you wait no longer. Send for your FREE copy today!

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DC
FLUIDS

Fluids . . . that stay fluid all the way!

In numerous engineering and technical uses, including precision instrument applications, the new liquid organo-silicon-oxide polymers known as Dow Corning Fluids are proving their marked superiorities over conventional oils.

These water-white mobile liquids remain fluid at arctic temperatures, and exhibit unusually low rate of viscosity change over a wide temperature range. They are heat stable, neutral in reaction, chemically inert, non-corrosive to metals.

The dielectric constant of the nonvolatile DC Fluids (those above 20 centistokes) is 2.7 to 2.8 and their dielectric loss is exceptionally low, remaining at less than 0.0001 over a wide frequency range. Inquiries for detailed information are invited.

DOW CORNING CORPORATION
BOX 592, MIDLAND, MICHIGAN

DOW CORNING FLUIDS COME IN TWO TYPES:

TYPE 200—commercially available in five viscosity grades—100, 200, 350, 500 and 1,000—in centistokes at 25°C.

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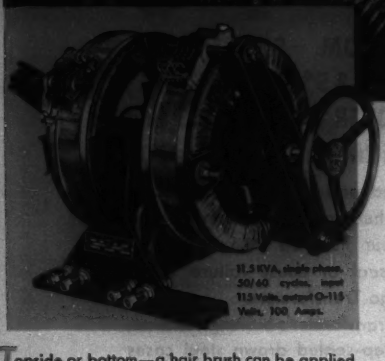

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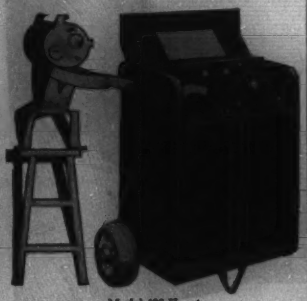

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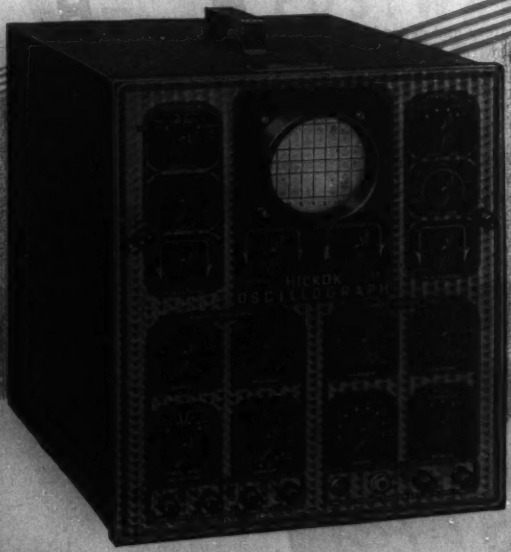

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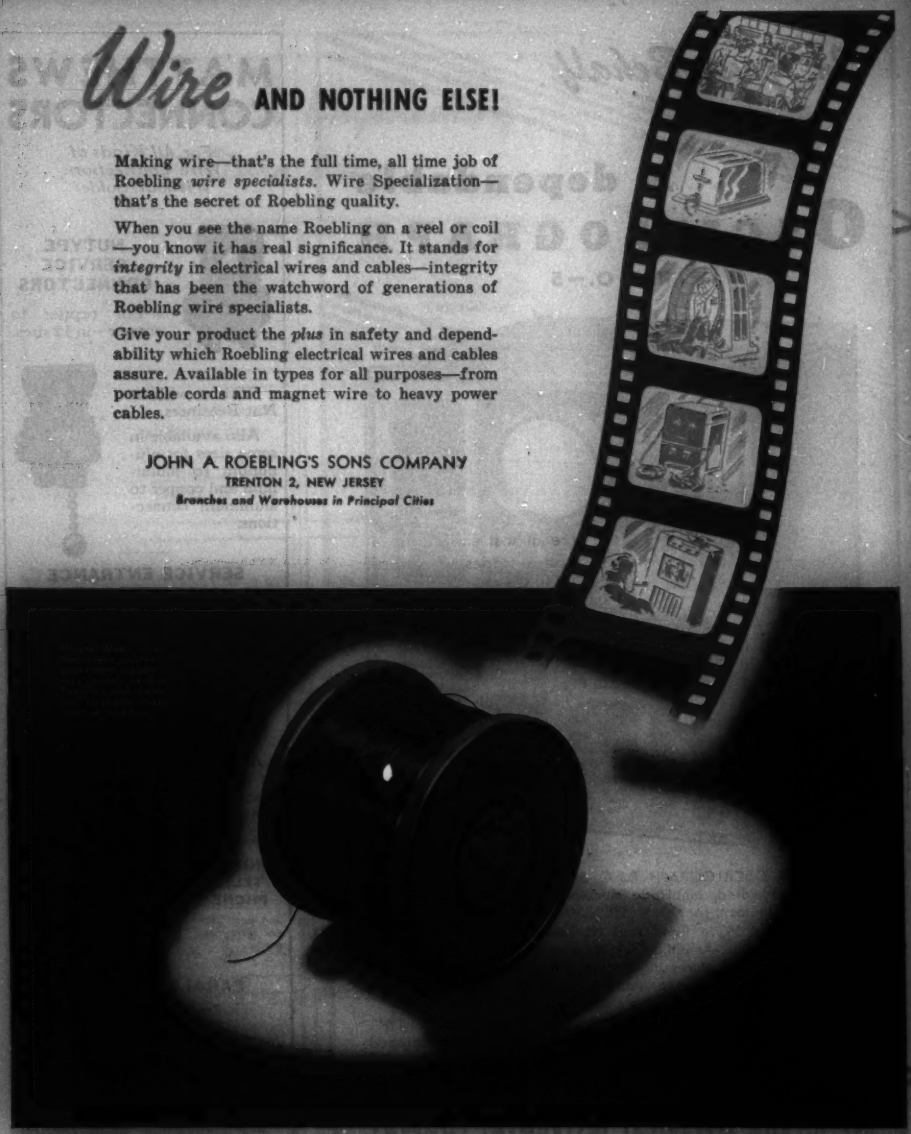

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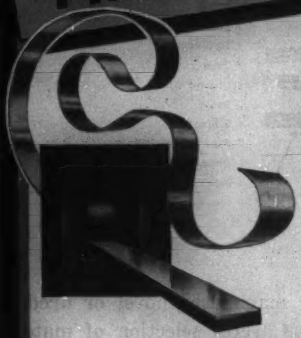

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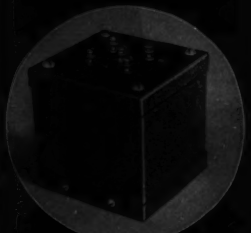

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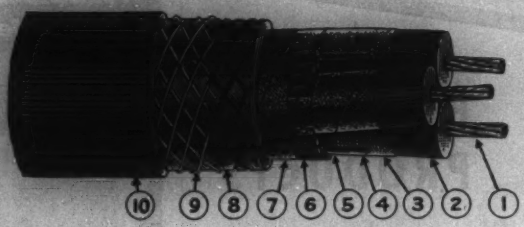

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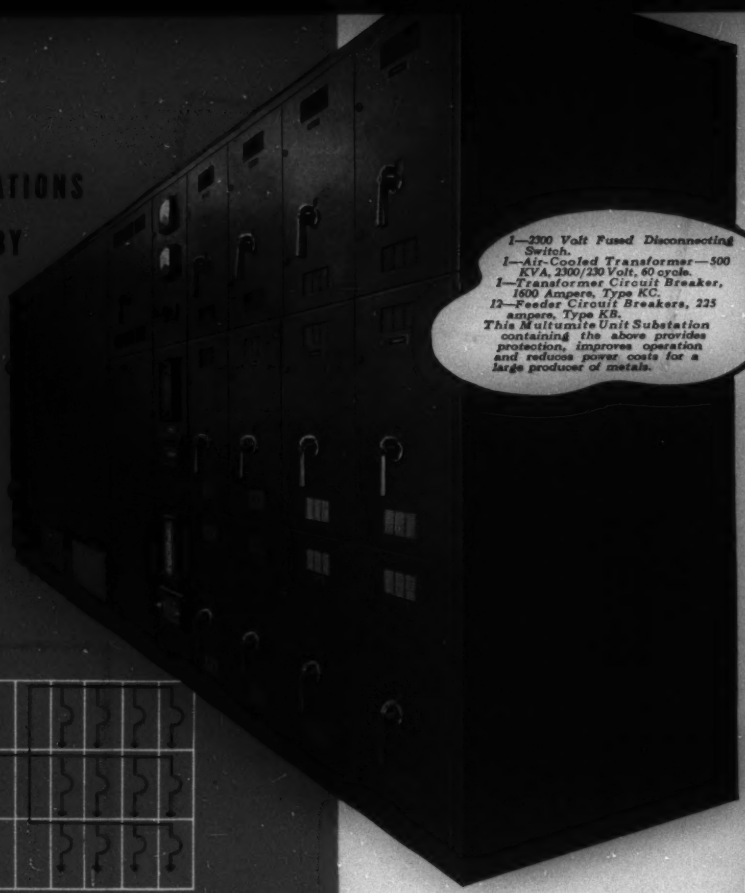

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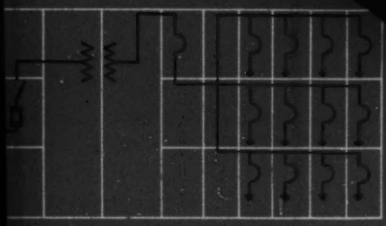

lowing its tradition of pioneering developments which bring new vantages to the user, I-T-E now makes available a real unit substation. e transformer and switchboard are constructed in a *single* completely closed unit, compact and functional. There is no throat connection, d no field assembly is required. This eliminates problems of aligning arate units.

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I-T-E DESIGN

It is the long established policy at I-T-E to supply switchgear to exactly meet the customer's needs. Rather than to merely approximate specific needs, as must be done within the limits of full standardization, I-T-E always provides custom-made quality—at no extra charge.

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OUR SWITCHGEAR

New INTERNAL-PIVOT

2½-INCH PANEL INSTRUMENTS ...1 INCH DEEP

UNIFORM MAGNETIC FLUX WITHOUT SEPARATE POLE PIECES ON MAGNET
SOFT-IRON CORE
Designed for thinness—but G-E engineers took advantage of the new magnetic materials to improve performance and add unusual values. Comol was selected for the magnet, and it thus became the basic part around which the internal-pivot element was designed.
MOVING COIL (WITH POINTER, BALANCE WEIGHTS, AND SPRINGS OMITTED TO SHOW DETAILS)
LARGE AIR GAP — 0.061 INCH
Moving element mounted on one-piece comol magnet

Extra Values That the Comol Magnet Gives You

AN air-gap flux density of approximately 2000 gausses—made possible by the comol magnet—means a magnetic field some 50 per cent stronger than that of the conventional chrome-steel magnet.

Higher Torque This greater magnetic strength provides a substantial increase in torque. Since the weight of the moving element is about the same as that of other designs, the torque-to-weight ratio is much higher.

Faster Response The greater flux density also allows the use of a larger air gap, which minimizes any tendency toward stickiness. Faster response, which is assured by the high torque and lightweight moving system, enables accurate readings to be taken more quickly.

Improved Performance Large-radius pivots and good damping are among the other good features in the internal-pivot design—a design that packs all-round fine performance in a small space. They all add up to an instrument that is well able to withstand abnormal vibration and shock and maintain its rated accuracy.

For complete information, ask our nearest office for Bulletin GEA-4064, which covers instruments for use in radio and communications equipment; or Bulletin GEA-4117, which describes those suitable for naval aircraft. *General Electric Company, Schenectady 5, N. Y.*

Type DW-53 d-c voltmeters, ammeters, and volt-ammeters. Designed to measure voltage and current in battery and battery-charging circuits on naval aircraft. Designed to meet all applicable Navy specifications.

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